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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

COLUMBUS MEETING

AT

THE OHIO STATE UNIVERSITY

MARCH 20, 21, AND 22, 1952

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AMERICAN PHYSICAL SOCIETY

COLUMBUS MEETING, MARCH 20, 21, AND 22, 1952

THE **312th meeting of the American Physical Society,** being the 1952 March meeting, will be held at Columbus (Ohio), in the Chemistry and Physics Buildings of the Ohio State University, on Thursday, Friday, and Saturday, March 20, 21, and 22, 1952. Our Division of Solid-State Physics, following its welcome practice of the last few years, adopts this meeting of the month of March as its own Annual Meeting, and in fact is providing more than half of the papers if one credits it with all of the ten-minute papers in its field. Our Division of High-Polymer Physics, which hitherto has held meetings concurrent with ours in others of the calendar months of the year, joins with us this March in Columbus. Other fields of physics are not so widely represented but are not missing.

The **headquarters hotel** is the Deshler-Wallick, to which requests for reservations (if hitherto unmade) should be made at once with mention of the name of the Society.

"To reach the University from the hotel, one boards a northbound trolley-bus on High Street opposite the hotel, bearing one of the following designations: N. High to Jeffrey, N. High to Blenheim, N. High to Arcadia." Get off at 17th Avenue; allow thirty minutes. Any southbound trolley-bus on High Street will bring you back to the hotel.

The **registration desk** will be located in Room 109 of the Physics Building. All members and guests of the Society are asked to register, and frequently to consult the bulletin board for notice of messages. All of the scientific sessions are in either the Physics Building or the Chemistry Building, which two stand side by side.

The **opening session** of the meeting, the only one which coincides with no other, will be held on Thursday morning. To make it representative of the interests of the Society and of its two Divisions here assembled, the Secretary has combined a paper in cryogenics (by J. G. Daunt) with one (by E. Guth) borrowed from the programme of the Division of High-Polymer Physics and one (by N. Bloembergen) borrowed from the Division of Solid-State Physics. This is a good place to mention the other invited papers of the meeting which do not pertain to the Divisions. Two of these, by D. M. Dennison and H. H. Nielsen, are survey papers in molecular spectroscopy—they are scheduled for Saturday afternoon; and on Friday morning two, by K. R. Atkins and R. J. Dolecek, in the field of cryogenics, and one by L. L. Foldy in nuclear physics.

Our **Division of Solid-State Physics,** whose appetite for invited papers seems never to slacken, has provided five half-day sessions of these, from one of which, incidentally, the Bloembergen paper of the opening session was lifted. Their general topics are: magnetic resonance (Thursday afternoon), effects of nuclear radiations on solids (Friday morning), recent theoretical work (Friday afternoon), low temperature phenomena (Saturday morning), second-order phase changes (Saturday afternoon).

Our **Division of High-Polymer Physics,** exacting less from the attention of its members, has provided two half-day sessions of invited papers. One of these (incidentally the one from which paper A2 was transferred) was evidently designed to enlighten the members of this Division about solid-state physics: by some juggling of scheduled hours which may not appeal to all, part though not the whole of this session has been rendered available to those who attend the symposia of the Division of Solid-State Physics. It will also be observed that the latter Division has encroached upon cryogenics: this illustrates the impossibility of cutting physics up into nonoverlapping fields.

Twenty-four **ten-minute papers** were supplied through the Division of High-Polymer Physics; about seventy belong pretty definitely in the field of solid-state physics, and obviously could not be scheduled to avoid coincidences with the solid-state symposia; the remainder of physics accounts for some twenty.

The **banquet of the Society** will be held on Friday evening at seven in the Deshler-Wallick Hotel, and the after-dinner speakers will be W. James Lyons, H. H. Nielsen, and J. C. Slater. Tickets at $3.50 will be on sale at the registration desk. Please use the form printed on the inside back cover page of this Bulletin to give the hotel an approximate advance idea of how many may be expected. After three o'clock on Friday afternoon, unpaid-for and uncalled-for tickets will be distributed to the first comers.

Entertainment for ladies is being prepared by wives of the staff of The Ohio State University, and will be announced on the bulletin board.

The **Council of the American Physical Society** will meet at five o'clock on Thursday afternoon in Room 101 of the Physics Building, unless contrary notice is sent to its members.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to a supplementary programme if the abstracts are received at the office of the Society not later than Friday March 14. Such papers as may be accepted will be given under the usual ten-minute rule at the end of Session T.

The attention of our members is drawn to the **Second Midwestern Conference on Fluid Mechanics,** to be held at The Ohio State University on the three days immediately preceding our meeting. Among the organizations which sponsor this meeting is our Division of Fluid Dynamics. Information is to be sought from Professor Geoffrey Keller, The Ohio State University, Columbus 10, Ohio.

Prospective meetings of the American Physical Society are scheduled as follows:

313. Washington, D. C. May 1–3.
314. Denver, Colorado. June 30, July 1–3.
315. St. Louis, Missouri. November 28–29.

General Rules for Presentation of Papers

The time allowed for the oral presentation of a contributed paper is ten minutes at most. The time allowed for the presentation of each invited paper is stated in the Bulletin. Papers on the "supplementary programme" are allotted to the respective sessions indicated by footnote: but the respective Chairmen are specifically empowered to cut the time allotted to each or any of such papers, or to read any by title.

Titles and abstracts of the papers contributed to the 1952 Columbus meeting are printed hereinafter, and in exactly this form they will stand in a future issue of *The Physical Review.* Errata will be printed on an adjacent page of *The Physical Review* if received not later than Friday, April fourth, by Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, New York. Do not send in the abstract marked with corrections: write out the corrections in the form "instead of . . . read. . . ." Do not add anything.

Speakers must retrieve their lantern slides before leaving the room in which the slides were shown. The Local Committee must not be burdened with the task of saving and returning them.

Karl K. Darrow, *Secretary*
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE 1952 COLUMBUS MEETING

(Personal names are those of invited speakers. DHPP stands for Division of High-Polymer Physics, and DSSP for Division of Solid-State Physics.)

Thursday Morning

A. Opening session: Daunt, Guth, Bloembergen. Chemistry 100.

Thursday Afternoon

B. DSSP (magnetic resonance): Norberg, Torrey, Pake, Hutchinson, Livingston. Chemistry 100.
C. General physics. Physics 110.
D. Effects of nuclear irradiation upon solids. Physics 100.
E. High polymer physics. Chemistry 161.

Friday Morning

F. DHPP: Heller-Pangonis, Beeman, Sutherland, Cobbs-Burton. Physics 100.
G. DSSP (radiation effects): Seitz, Blewitt, Fan-Lark-Horovitz, Parkins, Tyler, Bowers. Chemistry 161.
H. Atkins, Dolecek, Foldy. Chemistry 100
I. Magnetic resonance; semiconductors and rectifiers. Physics 110.

Friday Afternoon

J. DHPP: Smoluchowski, Shull, Weyl. Business Meeting of DHPP. Physics 100.
K. DSSP (recent theory): Slater, Pines, Zener, Brooks, Kittel. Chemistry 100.
L. Cryogenics. Physics 110.
M. Nonmetallic crystals. Chemistry 161.

Friday Evening

Banquet of the American Physical Society: Lyons, Nielsen, Slater. Deshler-Wallick Hotel.

Saturday Morning

N. DHPP: Simha, high polymer physics. Chemistry 161.
O. DSSP (low temperature phenomena): Pippard, Houston, Matthias, Stout. Business Meeting of DSSP. Chemistry 100.
P. Nuclear and molecular physics. Physics 110.
Q. Metals. Physics 100.

Saturday Afternoon

R. High polymer physics. Physics 110.
S. DSSP (second-order phase changes): Wannier, Tisza, Levy, Michels, Garrett. Physics 100.
T. Molecular spectroscopy: Dennison, Nielsen. Post-deadline papers, if any. Chemistry 100.
U. Transactions of crystals and light. Chemistry 161.

PROGRAMME

THURSDAY MORNING AT 10:15

Chemistry 100

(J. H. VAN VLECK presiding)

Opening Session

Welcome by the Chairman of the Department of Physics of The Ohio State University.
Response by the President of the American Physical Society.

Invited Papers

A1. The Low Temperature Properties of Helium 3. J. G. DAUNT, *Ohio State University.* (45 min.)
A2. Polymer Research as a Branch of Solid-State Physics. E. GUTH, *University of Notre Dame.* (45 min.)
A3. Recent Work on Magnetic Resonance, and Relaxation Effects in Ferromagnetic Resonance. N. BLOEMBERGEN, *Harvard University.* (45 min.)

THURSDAY AFTERNOON AT 2:30

Chemistry 100

(DUDLEY WILLIAMS presiding)

Invited Papers of the DSSP

B1. Nuclear Magnetic Resonance in Metallic Sodium. R. E. NORBERG, *University of Illinois.* (30 min.)
B2. Relaxation of Nuclear Spins by Diffusion. H. C. TORREY, *Rutgers University.* (30 min.)
B3. Hyperfine Structure in Free-Radical Paramagnetic Resonance. G. E. PAKE, *Washington University.* (30 min.)
B4. Paramagnetic Resonance Absorption in a Single Crystal of Manganese Fluoride. C. A. HUTCHINSON, *University of Chicago.* (30 min.)
B5. Pure Quadrupole Spectra of Solid Chlorine Compounds. RALPH LIVINGSTON, *Oak Ridge National Laboratory.* (30 min.)

THURSDAY AFTERNOON AT 2:30

Physics 110

(H. H. NIELSEN presiding)

General Physics

C1. On the Theory of the Electron. WALTER WESSEL, *USAF Institute of Technology.*—The mass operator proposed recently[1] is shown to lead to an additional magnetic moment of the electron of the order of 1/137 Bohr magneton. The exact determination still meets with the difficulties of handling the infinite matrices. By insertion of a simple finite and not wholly equivalent representation of the underlying commutator algebra, one obtains a moment which is too large by a factor 16/3 as compared with Schwinger's well-known value.[2] For analytical purposes the difference operator representation, introduced in a foregoing paper,[3] has been fully developed with the use of the model of the spinning electron of Rosen,[4] which is shown to be kinematically equivalent to the author's. Besides, for reasons of interpretation, the theory has slightly been modified by exchange of the vectors u_k and κ_k in the Hamiltonian.

[1] W. Wessel, Phys. Rev. **83**, 1031 (1951); Z. Naturforsch. **6a**, 478 (1951).
[2] J. Schwinger, Phys. Rev. **73**, 416 (1948); **76**, 790 (1949).
[3] W. Wessel, Z. Naturforsch. **6a**, 473 (1951).
[4] N. Rosen, Phys. Rev. **82**, 621 (1951).

C2. On the Order of Magnitude of the Signal Radius of the Electron. PAUL MOLMUD, *Clarkson College of Technology.*—According to Landé's theory of the electron,[1] the stationary electron has a potential $e/(r^2+a^2)^{\frac{1}{2}}$ and a field $er/(r^2+a^2)^{\frac{1}{2}}$ where a is the signal radius. To get some idea of the magnitude of this factor a, the following computations were performed: (1) The Hamiltonian for a hydrogen-like atom was perturbed by $H'=Ze^2(1/r-1/(r^2+a^2)^{\frac{1}{2}})$. The shifts in the $2S_{\frac{1}{2}}$ and $2P_{\frac{1}{2}}$

energy levels were computed by the methods of perturbation theory and the separation of these perturbed levels was equated to the experimentally observed Lamb-Retherford shift. This equation is satisfied when a is assigned the value of six classical electron radii.[1] (2) The electron is assumed to have an intrinsic magnetic moment of one Bohr magneton. The resultant magnetic field and the classical electric field bear an angular momentum which can readily be computed.[2] The gyromagnetic ratio of the electron can have the correct ratio only when a is assigned the value $\frac{2}{3}e^2/mc^2$, two-thirds of the classical electronic radius.

[1] A. Landé, Phys. Rev. **76**, 1176–79 (1949).
[2] See author's dissertation, Appendix IV (Ohio State University, 1951). Cf. E. David, Z. Physik. 125 (1948–49).
[3] F. A. Kaempffer, Can. J. Research **A28**, 336 (1950).

C3. The Semiclassical Franck-Condon Principle and Its Application to Complex Systems. MELVIN LAX, *Syracuse University and the Naval Research Laboratory.*—The semiclassical Franck-Condon principle follows from the more rigorous quantum-mechanical transition probability if a mean-value theorem approximation and closure are applied to the sum over final and average over initial vibrational states. In order to provide a test of the accuracy of the semiclassical formula as well as to lay the ground work for a number of applications, the following problem was considered: Absorption or emission by a complex system whose vibrational states are describable by normal modes, such that the configurational energy difference between two electronic states can be approximated by a linear expression in the normal coordinates. The absorption and emission spectrum are then found to be Gaussian curves with displaced peaks. Another problem investigated is the extent to which a complex system can, as is customary in Franck-Condon calculations, be replaced by a one-parameter system. It was established that if the electronic energy *difference* (whether linear in the vibrational coordinates or not) is a function only of a single parameter, then a one-parameter *description* is possible. However, this *description* is in general equivalent to a one-parameter *system* (harmonic oscillator) only if the resonant frequency of the oscillator is made temperature dependent.

C4. Phenomenological Quantum Electrodynamics with Magnetic Poles. M. AVRAMY MELVIN,* *Eastsound, Washington.*—Electrodynamics is here developed with the following generalizations: (A) The flux fields **B** and **D** are distinguished from the force fields **H** and **E**. (B) The usual restriction to the absence of free magnetic poles is *not* made. The treatment differs from that given by Dirac, in which the generalization (B) has been made, in that generalized symmetry and covariance requirements (including independence of a metric) are here met.[1] It differs from the phenomenological quantum electrodynamics of Jauch and Watson, in which the generalization (A) has been made, in the addition of (B) as well as in the consistent satisfaction of the generalized covariance requirements mentioned above. The theory is also covariant, with *invariant ponderomotive phenomena*, under a transformation from "electric" to "magnetic" quantities. The possible physical significance of this covariance will be discussed. One can do without the singular "strings," attached to the poles in Dirac's theory, by introducing an independent "magnetic" 4-vector potential in addition to the usual "electric" potential. Generalized gauge invariance holds. Lagrangian and Hamiltonian formulations are given. The theory is then quantized, and inferences drawn.

* Guggenheim Fellow, 1951–1952.
[1] M. Avramy Melvin, "Symmetry and affinity of electromagnetic fields, charges, and poles," Proc. Second Can. Math. Congress (Vancouver, 1949).

C5. On Thermal Expansion of Propylalcohol. GEORGE ANTONOFF.—All liquids expand with temperature following the same pattern.[1] They all show "kinks" at intervals in densities, vapor pressures, and allied properties. The kinks are perfectly reproducible in standard conditions, and conditions under which they are not reproducible are known. I worked so that my results dublicate substantially those of Sydney Young. In a recent paper[2] Kretschmer disputes my results. The case is quite analogous to that of the kink in benzene at 45 or 46°C, about which it is known that it can be well reproduced, and yet it disappears in conditions of work of Cohen and Buy.[3]

[1] Compt. rend. 3/XII (1951).
[2] C. B. Kretschner, J. Phys. Coll. Chem. **55**, 1351 (1951).
[3] Cohen and Buy, Z. physik. Chem. **B35**, 270 (1937).

C6. An Improved "Lock-In" Amplifier.* HENRY L. COX, JR., *The Ohio State University.*—A phase-detector or "lock-in" amplifier has been completed recently which offers linear response, simplicity of circuitry and adjustment, and a high degree of independence from variations of the reference signal amplitude and of vacuum-tube parameters. A square-wave reference voltage is used to minimize the undesired effects of nonlinearity of the detecting diode characteristic curves. While the basic instrument has unwanted response to noise components which are odd harmonics of the reference frequency, suitable filtering removes this minor defect. The instrument to be described was designed to operate at audio-frequencies but could be adapted for the lower radiofrequency range.

* Supported in part by a contract between the Geophysical Division of the Air Force Research Center and the Ohio State University Research Foundation.

C7. A Phenomenological Uncertainty Principle. JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories.*—The existence of a thermodynamic limit to the precision of any measurement follows from the facts that: (a) information is conveyed by making choices from an ensemble of alternatives for which an "entropy" is definable measuring initial freedom of choice and hence quantity of information when choices are made; (b) measurement chooses from an ensemble of possible results, thus yielding "physical" information; (c) either the informational entropy of physical information multiplied by Boltzmann's constant must be a lower bound to the thermodynamic entropy generated in acquiring it or the second law can be violated. Example: A quantity equiprobably between o and u is measured to fall within Δu. Then choice from $u/\Delta u$ alternatives was made at entropy cost ΔS not less than $k \ln(u/\Delta u)$. For preassigned experimental conditions maximum ΔS is well defined and $\Delta u \geq u \exp(-\Delta S/k)$. Individually sharp p or q is then undefined operationally on phenomenological grounds rather than quantal as for simultaneously sharp p and q. Speculation: Divergencies may originate in ascribing theoretically sharp values to operationally uncertain parameters.

C8. Relative Variation of DC and Pulse Emission from Mixtures of Rare-Earth Oxides.* E. N. WYLER AND F. C. TODD, *Battelle Memorial Institute.*—Coomes observed that good dc emitters are usually good pulse emitters, but the reverse is not necessarily true.[1] The resistance of an interface when present, electrolytic flow of barium, and gas bombardment of the cathode surface "can contribute" to the pulse decay of oxide-coated cathodes.[2] From experiments on mixtures of rare-earth oxides of the $4f$ series and from published results for oxide-coated cathodes, a correlation has been observed between the ratio of pulse to dc emission and the formation of solid solution of the components of a binary mixture in each other and in new phases of the two components. The nature of the mixtures has been analyzed by x-ray diffraction patterns. The dc and pulse emission currents from each mixture were checked and rechecked by alternate measurements in a diode with a platinum anode. Measurements were made on mixtures

for the full range of proportions of neodymium oxide with gadolinium oxide, and in some proportions on mixtures of dysprosium oxide with gadolinium oxide, and of terbium oxide with gadolinum oxide.

* This work was sponsored by Evans Signal Laboratory and Wright-Patterson Air Force Base.
[1] E. A. Coomes, J. Appl. Phys. **17**, 647–654 (1946).
[2] D. A. Wright, *Semi-Conductors* (John Wiley and Sons, Inc., New York, 1950), p. 119.

C9. Cathode Effects in Dielectric Breakdown. R. W. CROWE, A. H. SHARBAUGH, AND J. K. BRAGG, *General Electric Research Laboratory.*—The electron emission characteristics of the surface of the cathode used in the study of the electric breakdown of insulators have a fundamental bearing of electric strength observed. It has been suggested that formation of a negative space charge is the mechanism through which this influence is exerted.[1] This space charge is assumed to be supplied by field emission from the cathode. It distorts the field in the dielectric and causes breakdown at lower applied voltages than would be indicated by a knowledge of the intrinsic electric strength. These suggestions lead to a semi-quantitative account of the influence of certain properties of the cathode: for example, its vacuum work function and, in case of an aqueous electrolyte cathode, the concentration of the negative ion. They also provide for the time required for the breakdown process. These considerations indicate the sort of experiment which must be done to measure the intrinsic electric strength of condensed dielectrics.

[1] A. von Hippel and R. S. Alger, Phys. Rev. **76**, 127 (1949).

C10. $L\alpha_{1,2}$ and $L\beta_1$ Emission Lines of Copper and Zinc.* C. H. SHAW AND NATHAN SPIELBERG,† *The Ohio State University.*—Preliminary measurements of the shapes of the Cu and Zn $L\alpha_{1,2}$ and $L\beta_1$ emission lines, representing transitions from d bands to the L_{III} and L_{II} levels, respectively, have been completed on a new two-crystal vacuum x-ray spectrometer. Beryl crystals, cut along the $(10\bar{1}0)$ planes ($d=7.96$A), ground, polished, and etched, and having a (1, −1) width of 0.34 volt at 13.3A were used in conjunction with an Allen type photomultiplier[1] as detector. Comparisons with the corresponding $K\beta_{2,5}$ lines and with earlier photographic work bring out some interesting points. Certain operating data of the spectrometer will be presented.

* Supported in part by ONR.
† DuPont Fellow, 1950–1951.
[1] J. S. Allen, Rev. Sci. Instr. **18**, 739 (1947).

THURSDAY AFTERNOON AT 2:30

Physics 100

(F. SEITZ presiding)

Effects of Nuclear Irradiation upon Solids

D1. Fading Characteristics of Gamma-Induced Coloration in High Density Glass. ROBERT H. KERNOHAN AND GRACE M. MCCAMMON, *Oak Ridge National Laboratory.*—Specimens of a high density lead silicate glass suitable for gamma-shielding were measured for optical transmission characteristics. The specimens were then given varying dosages from a 300 Curie cobalt 60-gamma-source. Color centers were readily introduced. Transmission characteristics were measured as a function of time following irradiation. The gamma-induced coloration faded at room temperature, and this fading could be greatly accelerated by illuminating the specimens. All specimens nearly recovered their original transmission characteristics. The glass specimens were furnished by the Penberthy Instrument Company.

D2. Energy Levels in Ge Produced by Nucleon Bombardment. J. H. CRAWFORD, JR. AND J. W. CLELAND, *Oak Ridge National Laboratory.*—In an attempt to determine the precise nature and position of energy levels associated with nucleon bombardment produced lattice defects, the results of the phenomenological model of James and Lehman[1] have been reexpressed in a form more amenable for calculation of readily measured experimental quantities, namely, hole concentration and initial rate of change of hole concentration with trap introduction in P-type Ge. These calculations are compared with experiment. Equilibrium carrier concentrations are calculated from the law of chemical equilibrium and the condition of electrical neutrality under the assumptions (1) all chemical impurity levels are completely ionized, (2) classical statistics are valid throughout, and (3) annealing of lattice disorder is negligible. These calculations have been extended to include other ideas of energy level situation, notably those of James and Lark-Horovitz.[2] These models are used to calculate bombardment curves for N-type material and ratios of N-type slope to P-type slope in order to compare these models with experimental results.

[1] K. Lark-Horovitz, Reading Conference on properties of Semiconducting Materials, Appendix II, by C. W. Lehman and H. M. James.
[2] H. M. James and K. Lark-Horovitz, Z. physik Chem. **198**, 107 (1951).

D3. Slip Lines in Pile Irradiated Copper Single Crystals. R. E. JAMISON AND T. H. BLEWITT.—Single crystals of high purity (99.999 percent) copper were grown with random orientations (in vacua by the Bridgman method) in the form of tensile bars. These were individually irradiated in a pile with the fast neutron flux varied from 5×10^{17} to 8×10^{18} neutrons/cm^2. The slip lines formed by subsequent cold working were then studied. Pronounced differences in these lines and those in nonirradiated crystals were observed. For small strains the lines were found to occur in clusters and in some cases cross-slip lines appeared. For larger strains, a similar clustering of slip lines was observed with the initiation of slip in the latent system. The load-extension curves show a reduction in stress with the activation of the latent slip system, suggesting that the latent system hardens at a faster rate than the active system. All of these slip characteristics are similar to those observed in alpha-brass.[1,2]

[1] Maddin, Mathewson, and Hibbard, Jr., *Unpredicted Cross-slip in Single Crystals of Alpha-Brass*, Metals Tech. February (1948), T. P. 2331.
[2] V. Göler and G. Sachs, Z. Physik **55**, 581 (1929).

D4. The Effect of Neutron Irradiation of Metallic Diffusion. R. R. COLTMAN AND T. H. BLEWITT.—It has been previously reported[1] that neutron irradiation will substantially increase the rate of metallic diffusion owing to an increase in the number of Frenkel defects. The disordered system Cu_3Au was used as a tool in these studies as each atomic motion tended toward ordering. Electrical resistance was used as a criterion for measuring the ordering process. Observations showed that

the relaxation time for ordering was substantially decreased as a result of the irradiation. Further measurements have been made. X-ray Debye-Scherrer patterns were made of the irradiated sample and the size of the ordered domains were deduced from the half-breadth of the super lattice lines indicating an average value of 125A. This domain size indicates that the Frenkel defects have an appreciable path before anihilation.

[1] T. H. Blewitt and R. R. Coltman, Phys. Rev. **85**, 384 (1952).

D5. Comparison of Thermally Induced Lattice Defects in Germanium and Silicon with Defects Produced by Nucleon Bombardment.* W. E. TAYLOR, *Oak Ridge National Laboratory*.—Quenching high purity germanium from elevated temperatures induces large changes in the room-temperature conductivity. The changes, which were noted by earlier investigators,[1,2] are similar to the changes induced by nucleon bombardment[3] and are sufficiently large to require a change in the number of carriers for their explanation. Similar large changes were observed with silicon, again the changes were analogous to those resulting from nucleon bombardment. In germanium only electron traps were observed: The density of traps was proportional to $\exp(-W/kT_q)$, where T_q is the quenching temperature. Both hole and electron traps were observed in silicon. The traps are believed to be associated with Frenkel and possibly Schottky type defects which are in equilibrium at the elevated temperatures, and are retained at room-temperature on quenching. These are the same type of defects to which nucleon bombardment effects are attributed.[3] The energy of formation of the defects in germanium was found to be $W=(42{,}700-12.5T)$ cal/mole.

* Experiments done at Purdue University under a Signal Corps Contract.

[1] Lark-Horovitz, NDRC Report 14-585, November 1945.
[2] Theuerer and Scaff, J. Metal Tech. **191**, 51 (1951).
[3] Cleland, Crawford, Lark-Horovitz, Pigg, and Young, Phys. Rev. **83**, 312 (1951).

D6. Neutron Bombardment of a Copper-Beryllium Alloy. G. T. MURRAY AND W. E. TAYLOR, *Oak Ridge National Laboratory*.—The effect of bombarding a supersaturated solid solution of beryllium in copper with neutrons was investigated and compared with the effect of similar irradiation of unsaturated solid solutions. The hardness increased approximately 45 DPH and the electrical resistance increased approximately 10 percent in the copper-beryllium alloy after a bombardment of 2.3×10^{18} n/cm^2. For comparable exposures a hardness increase of 20 DPH and a resistance increase of 0.5 percent was observed in unsaturated copper solid solutions. The behavior of the copper-beryllium alloy specimens during bombardment and subsequent thermal aging indicated that clustering or nucleation of a precipitate phase had occurred during irradiation. Evidence is presented which, for this alloy, supports Mott's[1] hypothesis that the increase in electrical resistance during the early stages of thermal aging at low temperatures is the result of coherent scattering of the electrons by precipitate particles rather than a strain effect. The resistance increase resulting from neutron bombardment is also attributed to scattering of the electrons by precipitate particles.

[1] N. F. Mott, Discussion of Paper by Gayler, J. Inst. Metals **60**, 267 (1937).

D7. Diffusion Effects of Cobalt when Bombarded with Neutrons. GEORGE W. CALLENDINE, JR.,* VIRGINIA C. RIDOLFO, AND M. L. POOL, *Ohio State University*.—Cobalt 59 cylinders were irradiated in the nuclear reactor at the Oak Ridge National Laboratories. These cylinders were given a thin gold plate before irradiation. After plating, the cylinders were positioned in layers between 0.18-inch thick carbon disks. These disks after irradiation were found to be radioactive with Co-60. This activity decreases rapidly by a factor of about 4000 from the surface of the disk to the center. It is suggested that this Co-60 activity in the carbon results from a diffusion type of mass transfer of cobalt atoms caused by collisions between high energy neutrons and cobalt. One would anticipate a similar type of mass transfer for other materials irradiated with high energy neutrons. It would therefore appear advisable to electroplate the gold onto the cobalt cylinders after irradiation if one desires to eliminate Co-60 activity in the gold layer.

* Research supported by the AEC.

D8. A Technique for Self-Diffusion Measurements. DAVID B. LANGMUIR,* *National Research Council of Canada, Chalk River*.—By allowing neutrons in the N.R.X. thermal column to fall upon a tantalum strip through a slit in a block of cadmium, a sharply defined region of activity can be produced. The variation of activity A with distance x along the strip in the shielded region can be computed to be $A=A_0\exp(-\mu x/\theta)+(\mu x/\theta)Ei(-\mu x/\theta)$, where μ is the absorption coefficient of cadmium for neutrons and θ is the angle of collimation throughout which neutrons strike the cadmium. With $\theta=0.15$ radian, the activity drops by a factor of 10 in about .018 mm. After suitable heat treatment the edges of the active spot become fuzzy because of diffusion. The effect has been observed qualitatively by autoradiography, and quantitatively by grinding off sections on 4/0-metallographic emery paper, which can be inserted in a counter. The above formula has been quantitatively confirmed for unheated samples. After heat treatment the measured distribution follows the error function, as predicted by theory.

* USAEC Liaison Officer, Chalk River.

D9. Experiments in Silver Self-Diffusion.* R. D. JOHNSON AND A. B. MARTIN, *North American Aviation, Inc.*—The rate of self-diffusion in silver has been measured in polycrystalline and single crystal solvents using radioactive tracer techniques. Measurements have been made in polycrystalline solvents diffused at temperatures as low as 497°C, at which point grain-boundary diffusion appears to be the predominant process. Analysis of experiments with both type solvents in the temperature range 903°C to 640°C have yielded the expression $D=0.11e^{-40,400/RT}$ for the volume diffusion process. The use of single crystal solvents has enabled the extension of the volume diffusion results to temperatures as low as 545°C, although the relatively short time anneals used at these low temperatures have resulted in D values which are somewhat higher than the extrapolated high temperature data. Results will also be given for specimens diffused in the presence of intense proton bombardment at 715°C and 555°C, and compared with the results of other irradiation-diffusion studies.

* This paper is based on work performed under Contract for the AEC.

D10. Analysis of the Resistivity Changes Produced by Deuteron Irradiation of Copper, Silver, and Gold.* J. W. HENDERSON, H. G. COOPER, J. W. MARX, *University of Illinois*.—It is assumed that the resistivity increase which results from deuteron bombardment of metallic foils is proportional to the concentration, N, of interstitial-vacancy pairs produced; i.e., $\Delta\rho=KN$. The production of such pairs is described by the equation $dN=Adm-BNdn-C(N,T)dt$, where n is the number of incident deuterons per unit area; A is the number of pairs produced in unit volume per incident particle; B is the probability that a given pair is annihilated by the action of any one incident particle; and $C(N,T)$ represents a process of thermal recovery. If it is further assumed that the bombardment was carried out at such low temperatures that $C(N,T)$ is negligible, the resistivity increase may be described by the integrated expression $\Delta\rho=KA/B\times(1-e^{-Bn})$. This expression gives excellent agreement with

the data obtained by deuteron bombardment of foils of 99.95 percent Au, Ag, and Cu at −140°C, in the University of Illinois cyclotron. It is suggested that the phenomenological saturation value KA/B, given by this equation, may provide a significant reference point for determining low temperature radiation damage.

* Supported by AEC Contract AT (11-1) 182.

D11. Effect of Cyclotron Irradiation on Some Thermocouple Materials. A. ANDREW, M. R. JEPPSON, AND H. P. YOCKEY.—The effect of irradiation on the thermoelectric power of iron, constantan, chromel, alumel, platinum, and 10 percent rhodium platinum thermocouple wires has been measured at temperatures up to 500°C using the 40-Mev alpha-beam of the Crocker Laboratory Cyclotron. One section of a loop of wire was subjected to a temperature gradient while being irradiated. Measurement of the emf produced in this loop showed that the emf resulting from the irradiation was less than 3×10^{-7} volt per degree centigrade, the limit of measurement of the equipment. Two other experiments involving direct exposure of a thermocouple junction showed no measurable effect with changing irradiation intensities. Work is continuing on this problem at lower temperatures.

D12. Radiation Damage in Sodium Chloride.* DONALD WESTERVELT, *North American Aviation, Inc.*—The properties of sodium chloride crystals which have been irradiated with high energy alpha-particles or electrons are compared with those of crystals penetrated by x-rays, or additively colored. While regions penetrated by fast particles at first appear to contain only a high density of *F*-centers, after optical bleaching they develop a deep purple color similar to that of crystals slowly cooled after heating in sodium vapor. A purple color after electron irradiation was reported elsewhere,[1] and was attributed to the presence of colloidal sodium. The purple irradiated crystals can be completely bleached by warming, however, and this, combined with their chemical neutrality, clearly differentiates them from crystals containing excess sodium. It is suggested that the new lattice defects introduced are the result of displaced sodium in interstitial sites, thermal annealing then proceeding through recombination with positive vacancies. The annealing process is accompanied by blue luminescence similar to that which accompanies thermal annealing of photochemically produced *F*-centers. Some effects are discussed of these lattice defects on other properties of the crystal.

* Work carried out under contract with the AEC.
[1] D. E. McLennan, Can. J. Phys. **29**, 122 (1951).

D13. Effect of Deuteron Bombardment on the Electrical Resistivity of Copper, Silver, and Gold.* J. MARX, J. KOEHLER, AND C. WERT, *University of Illinois.*—Three-mil foils of 99.5 percent copper, silver, and gold were bombarded by 12-Mev deuterons from the University of Illinois cyclotron. The foils were maintained at an average temperature of −150°C; their temperature never exceeded −140°C during irradiation. The deuteron flux as determined by copper monitor wires was uniform to 10 percent over the target area. The resistivity was determined at −172°C for silver and gold, and at −174°C for copper after various amounts of irradiation up to 11.4 microampere hours per cm². The initial slope of the resistivity *versus* irradiation curve for gold was 2.5 times the initial slope for silver, and 3.0 times that for copper. Total resistivity changes were Cu, 1.2×10^{-7}; Ag, 1.7×10^{-7}; Au 4.8×10^{-7} ohm cm. The total percentage changes were: Cu 23.5 percent, Ag 31 percent, Au 47.2 percent. After bombardment, the foils were maintained for 40 hours at −171°C±3°C, during which time the resistivity decreased less than 1.0 percent for any specimen. We would like to thank R. D. Erickson, H. G. Cooper, and J. W. Henderson for their help.

* Supported by the AEC contract AT (11-1) 182.

D14. Conductivity of Deuteron Irradiated Germanium and Silicon.* J. H. FORSTER, H. Y. FAN, AND K. LARK-HOROVITZ, *Purdue University.*—The conductivity, σ, of low resistivity *n* and *p*-type germanium and *p*-type silicon has been followed during irradiation with 10-Mev deuterons under controlled conditions (known flux and temperature). *P*-type material with a carrier density of 9.8×10^{17}/cm³ shows a decrease in conductivity with a gradual decrease in slope, the conductivity approaching a limiting value. *P*-type material with a carrier density of 7.8×10^{18}/cm³ shows an increase in conductivity after irradiation. The conductivity of *n*-type germanium with a carrier density of 3.3×10^{17}/cm³ changes with deuteron irradiation as with neutron irradiation.[1] The initial rate of change in carrier concentration per incident deuteron per unit volume, $\Delta n/\Delta n_D$, as determined from the σ *vs* flux curve was about −11 for *n*-type germanium and about −4 for low resistivity *p*-type germanium. *P*-type silicon of initial carrier concentration $n=2.4\times10^{18}$/cm³ at 0°C showed an initial value of $\Delta n/\Delta n_D=-31$, and the conductivity decreases in the early stages at an exponential rate. These results will be discussed in terms of the model of James and Lark-Horovitz.[2]

* Supported by a Signal Corps Contract.
[1] Cleland, Crawford, Lark-Horovitz, Pigg, and Young, Phys. Rev. **83**, 312 (1951); Cleland, Crawford, Lark-Horovitz, Pigg, and Young, Phys. Rev. **84**, 861 (1951).
[2] James and K. Lark-Horovitz, Z. physik Chem. **198**, 222 (1951).

D15. Hardness of Deuteron Irradiated Molybdenum.* I. G. GEIB AND R. E. GRACE, *Purdue University.*—The hardness of Mo sheets, 0.005 inch thick, has been measured before and after annealing and before and after bombardment with 10-Mev deuterons of either unannealed or annealed specimens. Hardness numbers were obtained using a Tukon tester with Knoop indenter and 1-kg load. Annealing a cold rolled specimen 3 hours at 2250°F gives a decrease in Knoop hardness number from 269 to 158. Photomicrographs and x-ray diffraction patterns show recrystallization and grain growth resulting from this annealing. 4.7μ amp-hr deuteron bombardment gives no change in the hardness of a cold rolled specimen. 5.1μ amp-hr bombardment increases the hardness number of an annealed specimen about 12 percent. X-ray transmission and back reflection patterns of annealed specimens before and after bombardment show no difference in structure.

* Supported by AEC Contract.

D16. Displacements Produced by Electron Bombardment of Germanium.* E. E. KLONTZ AND K. LARK-HOROVITZ, *Purdue University.*—The threshold energy for removal of Ge atoms from their lattice sites by electron bombardment is about .63 Mev.[1] Irradiation[2] at 1.5 Mev of several *N*-type samples having resistivities from 10^{-3} to 10 ohm cm indicates that about 1 carrier is trapped per incident electron at liquid nitrogen temperatures. For higher temperatures the number of trapped electrons is smaller because of healing out accompanying the bombardment. At lower incident energies the number of trapped electrons is smaller because of smaller cross sections for displacement. Investigation into the healing process has been carried out by observation of changes in Hall and resistivity curves while heat treating after bombardment.

* Supported by AEC Contract.
[1] E. E. Klontz and K. Lark-Horovitz, Phys. Rev. **82**, 763 (1951).
[2] We are indebted to Professor Burton and Charles Scholer of the Notre Dame Radiation Chemistry group for these irradiations.

THURSDAY AFTERNOON AT 2:30

Chemistry 161

(J. B. NICHOLS presiding)

Contributed Papers of the DHPP

E1. A New Approximate Conversion Method for Relating Stress Relaxation and Dynamic Modulus. ROBERT S. MARVIN, *National Bureau of Standards.*—It is of interest to relate the results of transient and dynamic measurements of the mechanical properties of matter, both as a check on the results and to permit a unified presentation of mechanical behavior over a wide range of frequencies. The difference between the real part of the dynamic modulus at a radian frequency $1/t$, $G'(1/t)$, and the stress relaxation function at a time t, $\Psi(t)$, may be written

$$G'(1/t)-\Psi(t)=\int_0^\infty\left[\frac{\tau^2/t^2}{1-\tau^2/t^2}-e^{-t'\tau}\right]g(\tau)d\tau,$$

where $g(\tau)$ is the Maxwell distribution of relaxation times which can be evaluated approximately from either type of measurement by graphical differentiation. Since the terms on the left are nearly equal, the transformation from one to the other can be effected with a high degree of precision and with relative ease. Data on a high molecular weight polyisobutylene taken by a number of investigators as part of a cooperative program are used to illustrate the method.

E2. Correlation of Dynamic and Static Measurements on Rubber-Like Materials. II. R. D. ANDREWS, *Dow Chemical Company.*—Static modulus (relaxation of stress), dynamic modulus and dynamic loss measurements on rubber-like materials can all be correlated in terms of the relaxation time distribution which characterizes the particular material under consideration. In carrying out calculations to relate these properties to the relaxation time distribution or to one another, it is very convenient to have approximate relationships which can be conveniently used. The present paper extends the investigation of approximate relations begun in the first paper of this series. More general derivations are given of some of the specific results derived previously. Second approximation expressions are derived which differ from those obtained in the preceding paper. The distribution of relaxation times for a polyisobutylene sample is calculated from relaxation of stress data to illustrate the application of the second approximation expression for the static modulus case. Static modulus measured by creep experiments is related to a distribution function of retardation (or orientation) times. First and second approximation expressions which can be used in this case are derived.

E3. Viscoelastic Properties of Polymers by Phase Angle Measurements. R. D. SPANGLER.—Equipment has been devised to measure the mechanical phase angle of polymers. Specimens are subjected to forced vibrations of 20 or 30 cycles per second at stress levels up to the ultimate strength of the materials. Measurements can be made on molded plastic specimens, on polymer melts, and on monofilaments and cords. From phase angle measurements the viscous and elastic components can be calculated. The elastic component of some polymer melts has been shown to be approximately equal to the viscous component. Data will be presented for a number of plastics including FM 10001 Nylon, FM 3001 Nylon, "Lucite" acrylic resin, and "Alathon" polythene resin.

E4. Investigations on Plastics in a Large Range of Mechanical Frequencies. W. PHILIPPOFF, *Franklin Institute Laboratories.*—Shear experiments have been made on some plastics, including National Bureau of Standards polyisobutylene, at mechanical frequencies ranging from 10 cycles per second up to 12 hours per cycle, and the measurements of the properties in this range correlate well with measurements made in other ranges by the laboratories cooperating in the test program of the National Bureau of Standards on polyisobutylene. These results, obtained by the extension of the frequency range, contribute to the further understanding of the properties of plastics. Tests on filled rubber containing carbon show that the "box distribution" formula applies throughout the range investigated, which leads to further conclusions as to the mechanical behavior of rubber.

E5. Dielectric Properties of Liquids, Gels, and Solids at Audiofrequencies. II. Polyvinylchloride Plasticized by Di-2-Ethylhexylphthalate and Dimethylthianthrene. R. F. MILLER, E. R. FITZGERALD,* J. M. DAVIES,† AND W. C. SEARS,‡ *B. F. Goodrich Company.*—In order to provide a useful range of hardness-temperature characteristics, polyvinylchloride is plasticized by such polar liquids as di-2-ethylhexylphthaate and dimethylthianthrene. Pure polyvinylchloride has a 60-cps dipole maximum near 100°C, while these plasticizers behave similarly at −70°C and −20°C, respectively. Plasticized polyvinylchloride exhibits essentially a merger of these to a lower and broader maximum at an intermediate temperature depending on the amount and type of plasticizer. The maximum shifts to lower temperature with increase in plasticizer or decrease in frequency. Ionic loss, which becomes appreciable at temperatures above the dipole maxima, is reduced by stabilizers such as lead oxide and lead silicate. In studying these properties for improvement in electrical insulating applications, additional information has been obtained about the structure of polyvinylchloride and the method of plasticization. Measurements cover the range from 0 to 100 percent plasticizer, from −75 to +150°C, and dc through 15, 60, 1000, and 10,000 cps. Essentially static measurements of hardness show a relatively small variation at the temperature of the dipole maximum with considerable change in plasticizer content. Individual dipoles are closely associated with their neighbors so that a considerable number probably move together in response to either electrical or mechanical forces.

* Now employed at University of Wisconsin, Madison, Wisconsin.
† Now employed at Army Quartermasters Corps, Philadelphia, Pennsylvania.
‡ Now employed at University of Georgia, Athens, Georgia.

E6. Method for Determining Dynamic Mechanical Properties of Gels and Solids at Audiofrequencies; Comparison of Mechanical and Electrical Properties. EDWIN R. FITZGERALD AND JOHN D. FERRY, *University of Wisconsin.*—A method has been developed for measurements of complex shear modulus on samples ranging from soft gels to stiff solids at −50 to +150°C over the frequency range 25 to 5000 cps. A rigid tube with coils around the ends is suspended so that the coils are in radial magnetic fields. Alternating currents are passed through the coils and the consequent motion is modified by introducing a sample between the tube and a heavy inner core. From determinations of the mechanical impedance of the system with and without a sample the impedance of the sample alone is found. One transducer coil is placed in the arm of a bridge where it acts as an electrical impedance, Z_2', while the other parallels the bridge circuit. Z_2' is found for two current ratios in the coils and the mechanical impedance from the difference in electrical impedance values. By a proper

choice of sample dimensions a precision of ±2 percent is obtained. Experimental results are given for a National Bureau of Standards polyisobutylene sample and for a polyvinyl chloride-dimethylthianthrene gel (10 percent polymer by volume). The temperature and frequency variation of the complex shear modulus of the gel is compared with that of the complex dielectric constant at the same temperatures and frequencies, previously reported for this gel by Fitzgerald and Miller.[1]

[1] Paper presented at the 305th meeting of the American Physical Society at Washington, D. C. (April 27, 1951).

E7. Dynamic Mechanical and Electrical Properties of the System Polyvinyl Chloride-Dimethylthianthrene. JOHN D. FERRY AND EDWIN R. FITZGERALD, *University of Wisconsin.*—The complex shear modulus, $G^* = G' = iG''$, measured at different temperatures and frequencies, is reduced to a single reference temperature T_0 by plotting $G'T_0\rho_0/T\rho$ and $G''T_0\rho_0/T\rho$ against ωa_T, a_T being a reduction factor which expresses the temperature dependence of the mechanical relaxation times.[1] The complex dielectric constant ϵ^* is treated similarly by plotting $\sigma' T_0\rho/T\rho_0$ and $\sigma'' T_0\rho/T\rho_0$ against ωb_T, where the relative nonoptical elastivity, $\sigma^* = \sigma' + i\sigma''$, is taken as $1/(\epsilon^* - n^2)$, and b_T expresses the temperature dependence of the electrical relaxation times. For a polyvinyl chloride-dimethyl thianthrene gel, 10 percent by volume, a single curve is obtained for each component of G^* and σ^*, and the factors a_T and b_T are found to be identical over a wide range of time scale. The reduced dispersion functions are quite different, however. The distribution function of mechanical relaxation times may be calculated from either component of the reduced modulus, and the two results agree. A similar concurrence is found for the distribution function of electrical relaxation times, but the electrical and mechanical functions differ. The treatment is also applied to compositions of other concentrations.

[1] Ferry, Fitzgerald, Johnson, and Grandine, J. Appl. Phys. **22**, 717 (1951).

E8. The Relaxation Distribution Function in Polyisobutylene and Polyisobutylene-Decalin Solutions. LESTER D. GRANDINE, JR., EDWIN R. FITZGERALD, IVO JORDAN, AND JOHN D. FERRY, *University of Wisconsin.*—Measurements of the complex shear modulus of a sample of polyisobutylene distributed by the National Bureau of Standards have been made by the double transducer apparatus described in a previous abstract, from 25 to 5000 cps and over a wide range of temperatures. The results are reduced to a reference temperature by the use of reduced variables and the distribution function of relaxation times is calculated from both real and imaginary components. The relaxation distribution function is compared with that derived for solutions in decalin at various concentrations, from measurements of wave propagation, the single transducer, and stress relaxation following cessation of steady-state flow.

E9. Ultrasonic Investigation of Plasticized Polymethyl Methacrylate. R. G. CHEATHAM AND ALBERT G. H. DIETZ, *M.I.T.*—Polymethyl methacrylate of varying plasticizer content was examined by pulsing bursts of ultrasound through flat specimens of varying thickness over a wide range of frequencies and temperatures. It is fairly well known that the mechanical properties of various states of matter are related to the attenuation and velocity of transmission of ultrasound. Perhaps the least understood concepts are the relationships involved in attenuation measurements. The purpose of this research was to investigate the relationships between the velocity and attenuation of ultrasound and the mechanical properties. It was found that increased plasticizer content resulted in an increase in attenuation and a decrease in velocity of transmission. The plasticizer content varied in steps of 0, 5, 10, 20, and 30 percent. The plasticizer used was dibutyl phthalate. The frequency range covered was 0.414 mc to 4.85 mc, and the temperature range from −40°C to +85°C. The velocity decreases with increased temperature along a straight line, whereas the attenuation passes through maxima and minima while exhibiting a general rise in value with increase in temperature. The velocity generally increases with increase in frequency, but again the attenuation passes through maxima and minima while exhibiting a general rise with increased frequency. There are possible indications of hydrogen bonding. The ultrasonic measurements have been correlated with dielectric measurements over the same temperature range.

E10. Acoustic Properties of Rubber as a Function of Chemical Composition. WILLIAM S. CRAMER AND IRVING SILVER, *Naval Ordnance Laboratory.*—An experimental study was made of the bulk and Young's moduli of elasticity at selected audiofrequencies for various natural and synthetic rubber compositions. Both results are expressed in the form of a complex modulus, $E(1+i\eta)$, where η is the loss factor or loss tangent. The bulk data were obtained with a resonant water column at 30°C and 1530 cps. Observations were made of the change in Q and shift in resonant frequency when the sample is inserted in a pressure antinode of the column. The Young's modulus was calculated from measurements on the velocity and attenuation of progressive waves in thin rubber rods. These measurements were carried out at 30°C over the frequency range 1 kc/s to kc/s. Graphs are presented showing variations of acoustic properties as functions of type and amount of filler or plasticizer. Special attention was given to carbon black fillers ranging in size from 30 to 200 microns and to nonreinforcing fillers such as titanium dioxide and diatomaceous earth. In general, the real part of both moduli increased and the loss factors decreased with loading. The variations of the moduli with loading changed substantially with types of filler and of rubber.

FRIDAY MORNING AT 9:30

Physics 100

(E. GUTH presiding)

Invited Papers of the DHPP

F1. Explicit Light-Scattering Functions for Colloidal Solutions of Spheres. W. HELLER AND W. J. PANGONIS, *Wayne University.* (30 min.)

F2. The Small-Angle Scattering of X-Rays by Solutions of Macromolecules. W. W. BEEMAN, *University of Wisconsin.* (30 min.)

F3. Infrared Analysis of the Structure of High Polymers: Recent Developments. G. B. B. M. SUTHERLAND, *University of Michigan.* (30 min.)

F4. Studies of Rapid Crystallization in Polymers. W. H. COBBS, JR. AND R. L. BURTON, *Du Pont Company.* (30 min.)

FRIDAY MORNING AT 9:30

Chemistry 161

(CYRIL SMITH presiding)

Invited Papers of the DSSP: Radiation Effects

G1. Introduction to Irradiation Effects in Solids. F. SEITZ, *University of Illinois.* (15 min.)

G2. Radiation Effects in Copper Single Crystals. T. H. BLEWITT, *Oak Ridge National Laboratory.* (30 min.)

G3. Optical Properties of Irradiated Semiconductors. H. Y. FAN AND K. LARK-HOROVITZ, *Purdue University.* (30 min.)

G4. Changes Produced by Irradiation in the Steady-State and the Kinetic Properties of Metals. W. H. PARKINS, *North American Aviation.* (30 min.)

G5. The Thermal Conductivity of Non-Metals at Low Temperatures. W. W. TYLER, *General Electric.* (20 min.)

G6. Heat Conductivity of Quartz. R. BOWERS, *University of Chicago.* (20 min.)

FRIDAY MORNING AT 10:00

Chemistry 100

(J. G. DAUNT presiding)

Invited Papers in Cryogenics

H1. First and Second Sound in Liquid Helium. K. R. ATKINS, *University of Toronto.* (30 min.)

H2. Research of the Cryogenics Branch at the Naval Research Laboratory. R. L. DOLECEK, *Naval Research Laboratory.* (30 min.)

Invited Paper in Nuclear Physics

H3. The Electron-Neutron Interaction. L. L. FOLDY, *Case Institute of Technology.* (30 min.)

FRIDAY MORNING AT 10:00

Physics 110

(L. R. APKER presiding)

Magnetic Resonance: Semiconductors and Rectifiers

I1. Magnetic Resonance in a System Containing Two Magnetic Sublattices.* ROALD K. WANGSNESS, *U. S. Naval Ordnance Laboratory.*—A classical calculation has been made of the normal precession frequencies of a system comprising the magnetizations of the two sublattices. Demagnetizing fields and the effects of anisotropy were included, the latter being described by effective demagnetizing factors which were separately defined for each sublattice. Weiss molecular fields were used to represent the inter- and intralattice interactions which can be of either ferromagnetic or an antiferromagnetic character. The general result thus obtained includes the known special cases of ferromagnetic and antiferromagnetic resonance conditions.[1,2] In the ferromagnetic case, an additional high frequency resonance is predicted which corresponds to a precession in the exchange field where the magnetizations do not precess in phase. The application of these results to resonance experiments is considered.

* Supported in part by the ONR.

[1] C. Kittel, Phys. Rev. **73**, 155 (1948).
[2] T. Nagamiya, Prog. Theoret. Phys. **6**, 350 (1951); C. Kittel, Phys. Rev. **82**, 565 (1951); F. Keffer and C. Kittel (private communication).

I2. Paramagnetic Relaxation in Metals. ALBERT W. OVERHAUSER,* *University of California, Berkeley.*—The paramagnetic relaxation effects of electron spins in metals have been studied. A description for the spin relaxation of a degenerate electron gas was developed, and five interactions which contribute to this relaxation were considered in detail. The relaxation times to be associated with the following processes were calculated: (a) interaction with magnetic fields arising from lattice vibrations, (b) interaction with electric fields arising from lattice vibrations, (c) interaction with nuclear spins, (d) interaction with the spins of other electrons, and (e) interaction with the fields due to the translational motion of other electrons. Only first-order transitions caused by the above perturbations were considered, and with the exception of process (c), the electrons were treated by means of plane waves, corresponding to independent motion in a potential well of constant depth. The most important process is that due to (e). This relaxation time was found to be approximately inversely proportional to temperature and to have a value of one microsecond at room temperature. The influence of exchange and correlation energies on the relaxation times, and the energy absorption, line width, and saturation effects that would be expected in a resonance absorption experiment were also treated.

* Now at the University of Illinois, Urbana, Illinois.

I3. Radiation Produced in Germanium and Silicon by Electron-Hole Recombination. J. R. HAYNES AND H. B. BRIGGS, *Bell Telephone Laboratories.*—Radiation has been obtained by carrier injection in both germanium and silicon. Analysis shows that at room temperature the radiation intensity is sharply peaked at a wavelength which corresponds so closely to the best estimates of the energy gap that there is little doubt that it is due to the direct recombination of excess electrons and holes. The wavelength of the maximum of the radiant energy from germanium was found to decrease with decreasing temperature from room temperature to that of liquid hydrogen. This decrease is in quantitive accord with the temperature coefficient of the energy gap deduced from electrical resistivity and Hall measurements[1] ($\mathcal{E}_G - 0.72 = 10^{-4}T$ electron volts). The value of the half-intensity width of the radiation from germanium may be expressed by the emperical formula $W = 0.022 + 3kT$ electron volts over the temperature range investigated.

W. Shockley, *Electrons and Holes in Semiconductors* (D. Van Nostrand Company, Inc., New York, 1950), p. 335.

I4. Test of Transistor Equations. M. B. PRINCE AND F. S. GOUCHER, *Bell Telephone Laboratories.*—By measuring five parameters in a *n-p-n* junction transistor, *viz.*, the conductivities and diffusion lengths for minority carriers in the emitter and base regions and the width of the base region, an α for the transistor can be computed from theory.[1] Previous to this investigation two of the parameters associated with the thin *p*-layer had not been measured. We have been able to measure these parameters and thus to calculate an α. The quantity α was also obtained independently in two ways: (1) by measuring the collector current—emitter current characteristic, and (2) by measuring the apparent quantum efficiency of the transistor as a two-electrode device with the base floating.[1] Five experimental samples with significant variations in the five parameters were examined. The three values of α for each sample were found to agree within the experimental error.

[1] Shockley, Sparks, and Teal, Phys. Rev. **83**, 151–162 (1951).

I5. Probing the Space-Charge Layer in a *p-n* Junction. G. L. PEARSON, W. T. READ, AND W. SHOCKLEY, *Bell Telephone Laboratories, Inc.*—The potential distribution in the space-charge region in a germanium *p-n* junction was determined by measuring the zero-current potential of a pointed tungsten probe pressed against the space-charge layer where it comes to the surface of the specimen. The space-charge layer is wide compared to the area of contact of the point and may be thought of as a region of dielectric. When the point is at the natural potential of the dielectric, no current flows. When the point has a potential applied to it externally, a current flows which consists of injected carriers. The point was moved by dragging it with light pressure, using a Hilger interferometer movement and the zero-current potential measured as a function of distance for different reverse biases from 20 to 90 volts. The relationship $4\pi C = \kappa W$ between the capacity per unit area C and the width of the space-charge layer W was found to hold within experimental error over the measured range of voltages for a dielectric constant κ of 16.1. It was found that C varied as $1/V^{\frac{1}{3}}$ at low reverse voltages and as $1/V^{\frac{1}{2}}$ at large reverse voltages indicating a linear concentration gradient in the center merging into constant concentration regions at each side.

I6. High Temperature Reduced-TiO_2 Rectifiers.* A. E. MIDDLETON, C. S. PEET, O. J. MENGALI, AND R. C. SIRRINE.—Work on high temperature semiconductor rectifiers has been in progress for 2½ years at Battelle. An analysis of the relationship between properties of materials in rectifiers and obtainment of rectification, in addition to a point-contact rectification survey of selected semiconductors, was initially conducted. Subsequently, selected semiconductors were purified and made in semicontrolled impurity states. Resistivity, thermoelectric power, and rectification tests were used to classify the semiconductors. Reduced TiO_2 showed early promise for use in an area rectifier. Reduced-TiO_2 rectifiers have been prepared by (a) oxidizing titanium sheet in oxygen and in water vapor, and (b) preparing ceramic TiO_2, followed by reduction in vacuum (also hydrogen) and applying vaporized, electroplated, and metal wire counterelectrodes. Rectifiers with counterelectrode areas ranging from 0.0028 to 0.2 square inch were successfully made. The influence of the work function and type of counterelectrode in the dc characteristic have been studied up to 250°C. Thirty-six-volt reverses and 0.8-volt forwards at room temperature have been observed. Rectification persists up to 300°C. A comparison of Se, Cu_2O, and TiO_2 rectifiers reveals that the TiO_2 rectifier may satisfy the practical need for high temperature rectifiers.

* This work has been supported by Wright-Patterson Air Force Base.

I7. Analysis of High Temperature Reduced-TiO_2 Rectifier Characteristics.* C. S. PEET and A. E. MIDDLETON.—Analysis of typical high temperature reduced-TiO_2 rectifier characteristics indicates that the Schottky diffusion theory of rectification applies. The current-voltage characteristics and behavior of the barrier-layer capacity were studied as a function of temperature, applied voltage, and work function of the counterelectrode. The contact resistance was found by extrapolation of the current-voltage characteristic through zero voltage. The height of the potential barrier was calculated from the slope of the contact resistance *versus* temperature curve between room temperature and 200°C. The height of the potential barrier varies directly with the work function of the counterelectrode, indicating that the rectifying junction is at the interface between the reduced TiO_2 and the counterelectrode. Alpha, the experimental value of e/kT in the Schottky diffusion equation, was found to vary between 0.4 and 0.8 per volt, instead of being 40 per volt at room temperature. Analysis of the capacitive characteristics of the barrier as a function of voltage and temperature gave information regarding the barrier thickness and the number of current carriers in the barrier region. The occurrence of rectification at high temperatures is apparently due to a high Schottky diffusion potential.

* This work has been supported by Wright-Patterson Air Force Base.

I8. Thermoelectric Effects in Germanium at Low Temperatures.* H. P. R. FREDERIKSE, *Purdue University.*—The thermoelectric power of germanium (against lead) was measured in the temperature region between 10° and 85°K. The apparatus was designed in accordance with Borelius' method[1] (with three junctions of which two are at the same temperature). The sample was soldered between two copper blocks; one block was in thermal contact with the refrigerant bath, the other block could be heated. The temperatures of both junctions were measured by means of resistance thermometers (lead wires or carbon resistors). Two (*n*-type) antimony-doped germanium single crystals were investigated. The thermoelectric power was found to be several hundred microvolts per degree and could be described by $Q = aT$ in the impurity range ($T < 30$°K). Above this temperature the dependence is more complicated. The behavior is very similar to that observed in SiC, CoO, and V_2O_3.[2] The theory predicts for the thermoelectric emf of semiconductors the following expression: $Q = (k/e)(\ln RT^{\frac{1}{2}} - 5.32)$, in which R is the Hall coefficient. This formula gives good agreement down to $T \sim 150$°K,[3] but seems to break down at very low temperatures.

* Supported by Signal Corps Contract.
[1] G. Borelius, Ann. Phys. (4) **66**, 73 (1921).
[2] B. M. Hochberg and M. S. Sominski, Phys. Z. Sowjet **13**, 198 (1938).
[3] K. Lark-Horovitz, W. Scanlon, *et al.*, N.D.R.C. report 14. 585.

I9. Calculation of Magnetic Field Effect upon the Hall Coefficient of Impurity Semiconductors.* W. J. WHITESELL, II, AND V. A. JOHNSON, *Purdue University.*—A number of investigations have demonstrated the dependence of the Hall coefficient R of semiconductors upon magnetic field H. The theoretical treatment of this effect by Harding[1] employs the Lorentz solution of the Boltzmann equation and assumes that the mean-free-path l of conduction electrons is independent of energy. However, these electrons are subject to various types of scattering, particularly lattice scattering with an energy-independent mean-free-path and Rutherford scattering with a mean-free-path proportional to the square of the energy. Upon this basis, the integrals giving the dependence of R upon H have been evaluated with $l=l_I l_L/(l_L+l_I)$, where l_L is constant and l_I is proportional to E^2. The dependence of R upon H has been found as the proportion of impurity scattering rises from 0 to 100 percent. Generally, R decreases with increasing H, but the rate of decrease is dependent on the proportion of impurity scattering.[2] For the most part, the computed change of R with H is too small to agree with observation.

* Supported in part by Signal Corps Contract.
[1] J. W. Harding, Proc. Roy. Soc. (London) **A140**, 205 (1933).
[2] Case $l=l_I$ discussed in V. A. Johnson and K. Lark-Horovitz, Phys. Rev. **79**, 176 (1950).

I10. Infrared Absorption Band in Germanium.* R. J. COLLINS AND H. Y. FAN, *Purdue University.*—Infrared transmission of bulk germanium was measured up to 38 microns. The absorption coefficient of a high resistivity sample (39 ohm-cm) up to 15 microns was so low that it could not be reliably determined, it then begins to rise steeply with increasing wavelength showing a sharp maximum of 25 cm^{-1} at 29 microns. A sample with ~600 times higher carrier concentration gives a similar absorption coefficient curve, the values being only slightly higher. The curve for a sample with still higher carrier concentration and much higher absorption coefficient can be analyzed into two parts; a smooth curve of increasing absorption coefficient with increasing wavelength plus the curve for the high resistivity sample. This indicates that the curve for the high resistivity sample corresponds to an absorption band independent of the carriers and characteristic of lattice. The limiting frequency of the lattice vibration for a diamond type lattice is related to the elastic constants by an expression given by Born.[1] This relation is well satisfied by the frequency of the absorption peak.

* Work supported by Signal Corps Contract.
[1] M. Born, Nature 582 (1946).

FRIDAY AFTERNOON AT 1:45

Physics 100

(R. BUCHDAHL presiding)

Invited Papers of the DHPP

J1. Structure of Solid Solutions. R. SMOLUCHOWSKI, *Carnegie Institute of Technology.* (35 min.)
J2. Structure of Solids by Neutron-Diffraction. C. G. SHULL, *Oak Ridge National Laboratory.* (40 min.)
J3. Structure and Mechanical Properties of Glasses. W. A. WEYL, *Pennsylvania State College.* (45 min.)

Business Meeting of the Division of High-Polymer Physics

FRIDAY AFTERNOON AT 2:30

Chemistry 100

(J. H. VAN VLECK presiding)

Invited Papers of the DSSP: Recent Theory

K1. Electronic Wave Functions for Magnetism and Chemical Binding. J. C. SLATER, *M.I.T.* (30 min.)
K2. A Collective Description of Electron Interactions. D. PINES, *University of Pennsylvania.* (30 min.)
K3. The Physical Basis of Ferromagnetism. C. ZENER, *Westinghouse Research Laboratories.* (30 min.)
K4. Recent Calculations on the Alkali Metals. H. BROOKS, *Harvard University.* (30 min.)
K5. Theory of Antiferromagnetic Resonance. C. E. KITTEL, *University of California, Berkeley.* (30 min.)

FRIDAY AFTERNOON AT 3:15

Physics 110

(W. V. HOUSTON presiding)

Cryogenics

L1. Energy Levels of a One-Dimensional Bose Solid. H. W. LEWIS, *Bell Telephone Laboratories.*—A study has been made of the effects of anharmonicity and statistics on the energy-level structure of a one-dimensional solid whose atoms obey Bose statistics and are treated as point particles. (The same procedure applies to Fermi statistics, with a few changes of sign.) In order to study the effect of statistics, it is essential to introduce an anharmonicity into the interatomic force, thus to go beyond the usual description of the Debye waves. This is clear, since a solid composed of indistinguishable particles, interacting through attractive harmonic forces, will obviously collapse. One must therefore choose a potential with a finite range; for this work, Gaussian potentials were used, largely because one can then do all the integrals that occur. Using a Gaussian repulsion centered at the origin, plus a Gaussian attraction centered at some optimum interatomic distance, we then make a variational fit of wave functions of the usual Debye type, expressed in terms of their configuration space variables. We then symmetrize these wave functions to study the effect of statistics. The results will be discussed with reference in particular, to the anomaly in the specific heat of solid helium at very low temperatures.

L2. Relativistic Quantum Statistics of Thermal Excitations and Its Application to Condensed Systems at Very Low Temperatures. C. V. HEER AND J. G. DAUNT.—In systems of short range order for which quantum mechanics are applicable, i.e., for fluids at very low temperatures, the thermal excitations are energetically of magnitude $h\mu s$, where s is the velocity of sound and μ a parameter expressing the range of ordering. The quantum statistics of these thermal excitations are treated relativistically, using field theory methods analogous to those employed by Scheidegger and McKay,[1] but in which statistics the energy for the "creation" of excitations may be equal to or *less* than kT. It is shown that this treatment leads: (a) to a transition phenomena analogous to the degeneracies in Bose-Einstein and in Fermi-Dirac statistics; and (b), to the result that for long range order (e.g., in solids or in liquids helium II near 0°K), where $\mu \to 0$, the well-known phonon excitations are arrived at as a limiting case, both for field representations which commute and anti-commute. A parallel treatment is given for relativistic systems in which the "particular" nature of the system is stressed, and it is found that the degeneracy temperatures of such systems correspond to the transition temperatures of the previous models. Tentative applications are made to transitional phenomena in liquid He^4 and in liquid He^3, and to other phenomena occuring in such liquids very close to the absolute zero.

[1] A. E. Scheidegger and C. D. McKay, Phys. Rev. **83**, 125 (1951).

L3. Design and Performance of a New Type Heat Interchanger for Large Helium Liquefiers. J. NICOL, T. S. SMITH, C. V. HEER, AND J. G. DAUNT, *Ohio State University.*—A counterflow heat interchanger for exchanging between high pressure and low pressure helium gas flows at temperatures between 10°K and 90°K is described. The design is such that the low pressure flow is at right angles to the tubes carrying the high pressure gas, and is canalized through spaces formed by threading the high pressure tubes. A comparison is given of the computed performance with the observed results. Observations of the efficiency of the interchanger were made by incorporating it in a large helium liquefier in use in the Physics Department. This liquefier, constructed in the laboratory, is of the Kapitza type,[1] using as in the Collins machine[2] two reciprocating expansion engines, and has a production rate of 4 liters of liquid helium per hour.

[1] P. L. Kapitza, Proc. Roy. Soc. (London) **A147**, 189 (1934).
[2] S. C. Collins, Rev. Sci. Instr. **18**, 157 (1947).

L4. The NBS Liquid Level Indicator for Condensed Gases. W. E. WILLIAMS, JR. AND E. MAXWELL, *National Bureau of Standards.*—This instrument indicates the liquid level inside of a closed vessel and is especially designed for use at low temperatures with liquefied gases such as nitrogen, oxygen, hydrogen, and helium. It operates on a capacitance principle, and makes use of the difference in dielectric constants of the liquid and vapor. The sensing element is a cylindrical capacitor, whose capacitance is a function of the height of the liquid column. The sensing capacitor is one element of an automatically balanced bridge which both indicates and records the liquid level. An over-all accuracy of ± 1 percent has been obtained. The sensitivity is adequate for use where the difference in dielectric constants of the liquid and vapor is 0.05 or greater. The instrument also incorporates a control function, and supplies a controlled air pressure to a pneumatically operated value for maintaining the level at a predetermined point.

L5. Superconductivity of Thallium Isotopes. E. MAXWELL AND O. S. LUTES, JR., *National Bureau of Standards.*—The isotope effect has been observed in the superconductivity of thallium samples of mass 203.3 and 205.0. The difference in transition temperatures is $0.012° \pm .003°$. This would correspond to a mass temperature relation of the form $M^{0.61 \pm .15} T_c = \text{constant}$. $(dH/dT)T_c = 126$ oersteds/°K. The specimens were prepared by chemical reduction of isotopically enriched samples of Tl_2O_3 loaned by the Atomic Energy Commission. Measurements were made on duplicate samples by a magnetic method.

L6. Experiments with a Rotating Cylinder Viscometer in Liquid Helium. II. A. C. HOLLIS-HALLETT, *University of Toronto* (Introduced by M. F. Crawford).—In the experimental arrangement, the inner cylinder was suspended by a torsion fiber while the outer cylinder was rotated at various constant velocities in the range 0.1 to 3 cm/sec. Unlike the results obtained with ordinary fluids, the torque, produced by the rotating helium II upon the inner cylinder, was not found to be directly proportional to the velocity of rotation at any temperature between the lambda-point and 1.15°K. It has been found necessary to postulate the existence of a new type of frictional force in liquid helium II in order to explain the results; the force of mutual friction proposed by Gorter and Mellink is inadequate. Extrapolation of the results to zero velocity has given values of the viscosity of the normal component. These agree with the oscillating disk results between the lambda-point and about 1.6°K; but, at lower temperatures, the present results are significantly lower, suggesting, perhaps, that the accuracy of the existing data for the density of the normal component is less than has been supposed below 1.6°K.

L7. Free Energies and Phase Transition of a Cylindrical Superconductor.* PAUL M. MARCUS, *University of Illinois.*—The definitions of, and distinctions between the Helmholtz

and the appropriate Gibbs free energies for a cylindrical superconductor in a uniform longitudinal magnetic field, (field lines straight, arbitrary cross section) have been carefully discussed, taking account of the exact form of the field penetration according to the London equations. Free energy density formulas are derived, which are used to obtain the condition for the first breakdown of the superconducting phase and formation of a normal region, by considering the change of the total Gibbs free energy of the specimen. Full account is taken of the modification of the field distribution as the phase boundary pushes into the specimen. The condition found is, that the current density at some point on the surface must attain the same value as that at which a massive superconductor undergoes transition. For a thin specimen of convex cross section, this occurs at higher critical fields than for a massive specimen. This condition is definitely not that for complete transformation to the normal state, which occurs at still higher fields. The condition may also be expressed by saying that the Gibbs free energy density is spatially continuous through the phase boundary.

* Work supported by the ONR.

L8. Low Temperature Dielectric Behavior of Potassium Niobate.* R. PEPINSKY, R. THAKUR, AND C. MCCARTY, *The Pennsylvanic State College.*—Dielectric measurements of $KNbO_3$ by Matthias and co-workers[1,2] revealed the ferroelectric Curie point at 420°C and a further transition at 228°C. These investigators reported finding no significant variation in dielectric constant at temperatures below the latter point. Measurements in this laboratory at 10 Kc/sec on single crystals of $KNbO_3$, prepared without flux, do show a sharp peak in dielectric constant at about −50°C, as the temperature is dropped. The peak is observable in crystals of high purity and consequent low conductivity, and corresponds to an increase in dielectric constant from about 500 to nearly 1000. Between −50°C and −100°C the dielectric constant drops slowly, and from −100°C to −190°C it falls more rapidly to a value of about 100. The coercive field shows an increase as the temperature drops toward −50°C, becomes very large at that temperature, and then falls slowly as the temperature falls. The dielectric change is less pronounced and shifted upward by about 15° for measurements made from −190°C upward. The nature of this lower transition is under x-ray examination.

* Development supported by Office of Air Research.
[1] B. T. Matthias, Phys. **75**, 1771 (1949).
[2] B. T. Matthias and J. P. Remeika, Phys. Rev. **82**, 727 (1951).

L9. The De Haas-Van Alphen Effect in Tin.* G. T. CROFT, W. F. LOVE, F. C. NIX, *University of Pennsylvania.*—The de Haas-van Alphen effect has been observed in a spherical single crystal of tin $\frac{1}{16}$" D at 1.81°K. The torsional method was used where the difference in susceptibilities along the tetragonal Z-axis and the X-axis is measured. The angle between the tetragonal axis and the magnetic field was 45°. In order to remove the effects due to eddy currents, the galavnometer coil in the torsional suspension was made part of a negative feedback split photocell-amplifier circuit. The magnetic field was carefully regulated by a current control circuit utilizing a *Brown Converter*, permitting the period of the oscillations in tin to be resolved. Results are in fair agreement with data published by Shoenberg.[1] The period of the oscillations goes from approximately 26 gauss in the neighborhood of 6.3 kg, to approximately 50 gauss at 8.6 kg, while the amplitude of the oscillations increases by a factor of 5 over the same interval. A plot of $1/H$ at successive maxima in $x_n - x_z$ *versus* a set of consecutive intergers yields a linear relationship indicating that the oscillations contain a factor of the form $\sin[(\alpha/H)-\beta]$.

* Supported by the AEC.
[1] Shoenberg, Nature **8162**, 225 (1949).

L10. Magnetic Properties of Superconducting Tin-Bismuth Alloys.* W. F. LOVE, *University of Pennsylvania.*—Magnetization curves for spherically shaped superconducting alloys of Sn and Bi have been measured as a function of temperature and Bi content. The Bi is kept in solid solution at 135°C and quenched in liquid air just before taking measurements. With increasing Bi content (up to 12 at. percent Bi) the magnetic transition from superconducting to normal state becomes broader and the transition temperature increases uniformly. Alloys through 8 percent Bi show a better than 70 percent Meissner effect. A plot of the field at which penetration begins as well as that for which penetration is complete *versus* T^2 yields a straight line. In the former case the slope of this line decreases with increasing Bi content while in the latter case it rises rapidly.

* Supported by the AEC.

FRIDAY AFTERNOON AT 3:15

Chemistry 161

(F. SEITZ presiding)

Nonmetallic Crystals

M1. Electron Microscopic and Diffraction Studies of Some Paraffinic Sodium Soaps.* MORTON L. E. CHWALOW,† *Temple University.*—Electron microscopic investigations of the crystalline structures formed by the paraffinic sodium soaps, from sodium butyrate ($NaC_4H_7O_2$) through sodium stearate ($NaC_{18}H_{35}O_2$), show these to consist primarily of ribbon-like fibers which in the higher molecular weight soaps occasionally form closed rings. The maximum widths of these fibers decrease as the molecular weights of the soaps increase. As is known, sodium soap molecules align themselves parallel the long axes of their hydrocarbon chains and with their ionic ends adjacent to each other, thus forming bimolecular laminae. Present electron diffraction studies substantiate this and demonstrate that the long axes of the hydrocarbon chains are oriented essentially normal to the planes of the above noted ribbon-like fibers. Knowledge of this plus analysis of the van der Waals forces acting between the adjacent hydrocarbon chains and the forces prevailing in the ionic layer, lead to a direct explanation of the structures and structural changes observed electron microscopically.

* Materials and equipment (RCA) were provided by Socony Vacuum Laboratories.
† Present address: Frankford Arsenal Philadelphia, Pennsylvania.

M2. Effect of Lattice Imperfections upon X-Ray Diffraction and Linear Dimensions of Crystals.* P. H. MILLER, JR., AND B. R. RUSSELL, *University of Pennsylvania.*—Assuming radial distortion of a symmetric cubic crystal around a vacancy (or interstitial atom) at the origin, the relative change

in lattice parameter calculated from the shift in the x-ray diffraction maxima is of the general form $\Delta d/d = \{(\Sigma l)(\Sigma l f(r)) - N(\Sigma l^2 f(r))\} \div \{(\Sigma l)^2 - N(\Sigma l^2)\}$, where $f(r)$ is the relative change in length of the lattice vector $r = a(l^2+m^2+n^2)^{\frac{1}{2}}$, and the summations are over lmn of the N lattice points. When $f(r)$ is taken as Aa^3r^{-3} and n, such defects occur in the crystal. It is found that $\Delta d/d = 2.0(4/3\pi A)n/N$, allowing a 30 percent reduction as a result of the random distribution of the defects.[1] The macroscopic crystal expansion for this case, however, is only one-half as great so that the observations of Berry[2] and Strelkow on AgBr cannot be explained as a result of a predominance of Frenkel defects.

* This work supported by ONR.
[1] This equation corrects an error in the abstract previously submitted, Am. Phys. Soc. Bulletin **26**, No. 6, D4.
[2] C. R. Berry, Phys. Rev. **82**, 422 (1951).

M3. Structure of Ordered Phase of Ag_2HgI_4.* C. E. Olsen and P. M. Harris, *The Ohio State University.*—As a result of the development of a suitable technique, single crystals of $\beta-Ag_2HgI_4$ have been grown. As a result of interest in the well-known transformation at 52°C observed by Ketelaar[1] and in the structure proposed by him for the temperature (β) modification of this substance, its structure has been reinvestigated. Powder x-ray diffraction data for this β-phase show only lines assignable to a cell of cubic dimensions, even at liquid air temperatures. However, a number of weak lines (correspond to a cell with a_0 twice that of Ketelaar. Some of these have been reported by Frevel.[2] Single crystals of the β-phase exhibit $D_{2d}^{12}(\bar{4}\,2m)$ symmetry. Weissenburg x-ray goniometric measurements appear to require a body-centered tetragonal cell with $a_0 = 6.32$A° and $c_0 = 12.64$A°. This corresponds to a cell with just twice the c_0 reported by Ketelaar. The structure will be discussed.

* Assisted by funds from ONR.
[1] Ketelaar, Trans. Faraday Soc. **34**, 874 (1938).
[2] L. K. Frevel and P. P. North, J. Appl. Phys. **21**, 1038 (1950).

M4. Crystal Structure of Cesium Monoxide.* Khi-Ruey Tsai and P. M. Harris, *The Ohio State University.*—Single crystals of cesium monoxide (Cs_2O) have been prepared for the first time. The anti-$CdCl_2$ layer structure (D_{3d}^5d) of the monoxide previously suggested by Helms and Klemm[1] from powder data has been confirmed from single crystal x-ray diffraction work. The cell constants (hexagonal indexing) and interionic distances have been found to be: $a = 4.256$A, $c = 18.99$A, $u = 0.242$, $Cs^+ - O^= 3.01$A, and $Cs^+ - Cs^+ = 3.77$A, respectively, compared with $a = 4.27$A, $c = 18.8$A, $u = 0.25$, $Cs^+ - O^= 2.91$A, and $Cs^+ - Cs^+ = 3.99$A as observed by Helms and Klemm. The orange-yellow crystals of the monoxide tend to develop the basal planes and exhibit shearing disorder when freshly pulverized. The structures and characteristics of some of the suboxides of cesium will also be discussed. Interest in this substance arose due to its possible occurrence in the Ag−O−Cs photocathode.

* Work supported in part by a fellowship grant from The Ohio State University Research Foundation to the University for Aid in Fundamental Research and under contract with the Engineer Research and Development Laboratory, Fort Belvoir, Virginia.
[1] A. Helms and W. Klemm, Z. anorg. u. allgem. Chem. **242**, 33 (1939).

M5. Charge Distribution and Vibration Amplitudes in LiH and Li D. C. K. Stambaugh* and P. M. Harris, *The Ohio State Univeristy.*—Intensities of Laue-Bragg scattering of CuK alpha x-rays from powder samples of LiH and LiD have been made from 20°K to room temperature. From the temperature coefficient of scattering the amplitudes of vibration have been evaluated. The corresponding characteristic temperatures are 851°K and 638°K for LiH and LiD, respectively. Charge distributions in the ions have been evaluated and compared with those calculated by Ewing and Seitz.[1] The variation of the charge distribution with temperature will be discussed.

* Major, USAF, Los Alamos Scientific Laboratory.
[1] D. H. Ewing and F. Seitz, Phys. Rev. **50**, 772 (1936).

M6. Structure of Graphitized Carbon Blacks. Edward A. Kmetko, *University of Buffalo.*—Previous electron microscopic studies of a carbon black (Thermax) showed that the particles lose their spheroidal forms during graphitization and assume shapes exhibiting polygonal outlines.[1] In this paper more detailed investigations of such structures are reported. Thermax carbon black (particle size ~3000A), heat treated to 3000°C in an atmosphere of nitrogen, was dispersed in a thermosetting resin. Formvar replicas of fracture surfaces were made by a variation of the usual procedure. Electron micrographs of these replicas show partial view of polyhedra which appear to have a high degree of symmetry and whose facets appear consistent with the symmetry of the aromatic lattice. All the projected views of the graphitized particles can be generated from a single type of polyhedron. Therefore, it seems probable that all carbon black particles during graphitization crystallize into a single form. In the case of another black of somewhat smaller size (*P*-33) direct views of the particles themselves show not only the same general features, but indicate clearly that the polyhedral structure extends throughout the body of the particle.

[1] Ragoss, Hoffman, and Holst, Kolloid-Z. **105**, 118 (1943).

M7. Mechanism for Self-Diffusion in Graphite.* G. J. Dienes,† *North American Aviation, Inc.*—The mechanism for self-diffusion in single crystals of graphite has been examined theoretically. Calculations for vacancy and direct interchange mechanisms are based on atomic interactions within the graphite hexagonal layers. These interactions are obtained from the known systematic change of carbon-carbon bond strength with interatomic distance. In order to be able to calculate the energy of formation of an interstitial carbon atom a potential function has been devised to account for interaction between the planes. This potential function consists of two terms, a Van der Waals' attraction and an exponential type repulsion. The adjustable constants have been evaluated from known physical data.

Comparison of the total activation energies for self-diffusion via vacancies, direct interchange, and interstitial atoms shows clearly that vacancy diffusion is the preferred mechanism. The activation energy for self-diffusion by means of vacancies is estimated to be 160 kcal/mole with 90k cal/mole required for the formation and 70 kcal/mole for the motion of vacancy. The present theoretical treatment is not applicable to diffusion along grain boundaries or pores.

* This work was supported by the AEC under contract AT-11-1-GEN -8
† Now at Brookhaven National Laboratory, Upton, Long Island, New York.

M8. The Electrical Conductivities of Natural Graphite Crystals. W. Primak and L. Fuchs, *Argonne National Laboratory.*—General agreement exists in the literature concerning the value of the "*a*" axis conductivity of graphite. However, measurements and estimates of the "*c*" to "*a*" axis conductivity ratio ranging from 10^{-2} to 10^{-5} have been reported. Graphite crystals (which are somewhat imperfect) have been separated from graphite-bearing crystalline limestones from northeastern North America. Measurements of potential drops and potential distributions on the surfaces of these graphite crystals carrying electric current show their "*c*" to "*a*" axis conductivity ratio to be approximately 10^{-2} and in no case less than 1.7×10^{-3}.

M9. Development of the Korringa Method for Energy Band Calculations. R. J. Harrison, *Battelle Memorial Institute.*—The Korringa method for determining electronic energy levels in crystals, which we have restated in terms of a scattering matrix formalism,[1] has the computational advantage that the part of the calculation which is concerned with meeting the periodic boundary conditions implied by the Bloch theorem may be performed once and for all for a given lattice type. For this purpose one evaluates the components

of a certain matrix $\mathbf{S}_B$, which is a function of the Bloch wave vector $\mathbf{k}$ and the energy E. In the other part of the calculation, which depends on the particular potential, V, within an atomic polyhedron, one determines $E(\mathbf{k})$ from a matrix equation connecting $\mathbf{S}_B(\mathbf{k}, E)$ and the scattering matrix $\mathbf{S}_V(E)$. In preparation for the specific application of this method, besides computing the elements of $\mathbf{S}_B$ for cubic lattices we have been exploring the formalism itself by considering certain special cases in detail. In particular we have examined the extreme cases of the "tight binding" and the "nearly free" electron approximations. These show features which are of intrinsic interest as well as relevant in testing the general method.

[1] R. J. Harrison, Phys. Rev. **84**, 377 (1951).

M10. Optical Polarization in Single Crystals of Tellurium.* JOSEPH J. LOFERSKI AND PARK HAYS MILLER, JR., *University of Pennsylvania.*—The transmission of polished single crystals of tellurium has been observed as a function of the polarization of the incident radiation. The position of the absorption edge and the amount of radiation transmitted differ with the direction of polarization. For radiation polarized with the E vector perpendicular to the C-axis of the crystal, the absorption edge lies at 3.7μ and the transmission beyond the edge is about 34 percent for a sample 0.034 cm thick; if the E vector is parallel to the C-axis of the crystal, the edge has shifted to 3.3μ and the transmission has dropped to 18 percent. The index of refraction of the material, which varies between 5.0 and 7.0 in the region from 4.0μ to 8.0μ, was determined by measuring the deviation of a beam of unpolarized light occurring in a small angle prism. Computation of the refractive index from the reflected radiation yields a value of about 5.

* This work supported by the ONR.

FRIDAY EVENING AT 7:00
Deshler-Wallick Hotel
(J. H. VAN VLECK presiding)

Banquet of the American Physical Society

After-dinner speakers: W. J. Lyons, H. H. Nielsen, and J. C. Slater

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SATURDAY MORNING AT 9:30
Chemistry 161
(L. M. DANNIS presiding)

Invited Paper of the DHPP

N1. The Viscosity of Concentrated Macromolecular Solutions. R. SIMHA, *New York University.* (30 min.)

Contributed Papers

N2. Self-Diffusion and Bulk Viscosity of High Polymers.* F. BUECHE, *Cornell University.*—In spite of its fundamental importance for an understanding of the physical properties of solid polymers, little is known about the rate of molecular diffusion in such systems. This paper will outline some results obtained from radioactive tracer measurements of the self diffusion constant, D, in polystyrene and poly n-butyl acrylate. A theoretical treatment of its relation to η, the bulk viscosity, will also be given. The experiments confirm a theoretically derived relation that $D \times \eta$ equals a constant composed of known quantities. Moreover, simple considerations have led to a relation for the bulk viscosity of solid polymers which agrees with experimental data available for polystyrene and polyisobutylene. Some success has been achieved in evaluating the segmental jumping frequency from a knowledge of bulk viscosity. The values thus found are in substantial agreement with those inferred from dielectric data—at least at the so-called second-order transition temperature.

* This work was supported by a contract with the R.F.C., Office of Rubber Reserve in connection with the U. S. Government's synthetic rubber program.

N3. The Effect of Diluents on the Second-Order Transition and Flow Properties of Polystyrene.* T. G. FOX, *Rohm and Haas Company.*—Volume dilatometric data on polystyrene mixed with each of thirteen low molecular weight diluents differing widely in their chemical nature have been obtained over broad ranges in temperature and composition. Viscometric measurements over the entire composition range have also been made for mixtures with dibenzyl ether. Up to about 30 percent of diluent, the second-order transition temperature (T_g) is depressed by an amount that is approximately proportional to the *volume fraction* of diluent added. When the data are represented in this way, the effects of the various diluents employed here are indistinguishable. At higher concentrations of diluent, the depression of T_g is much less than the above-mentioned linear relationship would predict. The dependence of T_g on composition closely parallels corresponding data on the lowering of the viscosity-temperature coefficient for polystyrene-dibenzyl ether mixtures. No correlation exists between the T_g-composition relationship and the S-shaped curves obtained in plots of the logarithm of the viscosity at a given temperature *vs* the composition for polystyrene-dibenzyl ether mixtures.

* This work was carried out at Cornell University, in connection with the Government Research Program on Synthetic Rubber under contract with the Office of Rubber Reserve, Reconstruction Finance Corporation.

N4. The Effect of Cross Linking on the Second-Order Transition Temperature of Polymethyl Methacrylate. S. LOSHAEK, *Rohm and Haas Company.*—The second-order transition temperature (T_g) of methyl methacrylate copolymerized with zero to 100 percent of (1) ethylene glycol dimethacrylate, (2) decamethylene glycol dimethacrylate, (3) 2,2-dimethyl-propanediol-1,3 dimethacrylate, and (4) 2-ethyl-2-butyl-propanediol-1,3 dimethacrylate have been determined by volume dilatometric measurements. The foregoing cross linkers were chosen to demonstrate first, the effect of increasing the length of the carbon chain between functional groups and second, the length of the side chain. There is a marked dependence of T_g on the structure of the cross linker molecule for a given concentration of the latter. Since T_g of the polymers formed from 100 percent of (2) and (4) is lower than that of pure polymethyl methacrylate, the possibility of a maximum T_g at some composition appears. The results can be rationalized if it is assumed that T_g is raised by the presence of cross

links and is at the same time lowered by an internal plasticization effect, the latter being dependent on the average composition and structure of the comonomer.

N5. Strain-Temperature Studies of Transitions in Rubbers.* R. J. DERENTHAL, F. P. BALDWIN, AND R. L. ANTHONY, *University of Notre Dame.*—Previously reported studies of the apparent second-order transition in rubbers by the length-temperature method (constant stretching load on sample) indicated an unusual dependence of the transition temperature, T_L, upon the initial tension strain, ϵ_0, of the sample. T_L was found to first increase as ϵ_0 was increased from zero to the thermoelastic inversion extension (about 7 percent), then to decrease with further increase in ϵ_0; finally, for some rubbers, T_L appeared to level off at higher extensions. These studies have been continued. In addition, a study of the dependence of the transition temperature upon shearing strain was undertaken. Results for several rubbers indicate no dependence of the transition temperature upon initial shearing strain for strains ranging from 0 percent to about 13 percent, in sharp contrast to the behavior observed in length temperature studies. The experimental methods employed in this work will be described, and the results obtained from both types of measurements will be discussed. It is not yet possible to specify the frequency spectrum for any of the materials studied (Cellophane, Nylon, and vinylidene chloride copolymers) because many of the patterns exhibit multiple effects. While the amplitude is generally decreasing with frequency secondary maxima appear in various parts of the record. These results are consistent with our earlier interpretation of this noise as arising from the motion of clusters of ions.

* Supported in part by the ONR.

N6. Random Noise in Dielectrics, II. HERBERT BAUSS AND R. F. BOYER, *The Dow Chemical Company.*—The fluctuating currents previously observed on applying a steady voltage to a number of polar polymers have been investigated further, both as regards temperature dependence and frequency spectrum of the noise. The effect diminishes with temperature but does not disappear on going through the second-order transition temperature. In the case of Nylon and a vinylidene chloride—vinyl cyanide copolymer, the noise almost vanishes at −75°C but reappears when the specimen is warmed to room temperature. Thus far, the frequency spectrum has been studied in various wave bands up to 3000 cycles per second. The random current from the sample was recorded on a tape recorder so that the same sequence of signals could be studied over various frequency intervals by using a band pass filter. This was considered necessary because the character of the noise appears to change with time.

N7. Dielectric Breakdown of Polymers Under Prolonged Stress. CARL G. BRODHUN.—The life of electrical insulation subjected to continuous electrical stress depends on the magnitude of the stress. Plots of electrical stress *vs* time to rupture resemble mechanical endurance curves. When corona is present, its effects are superposed on the effects caused by the dielectric stress and thus causes an inflection on the endurance curve. It is shown experimentally that breakdown because of corona attack is progressive, and apparently universal for solid dielectrics. Polymeric materials studied included "Alathon" polythene resin, "Teflon" tetrafluoroethylene resin. Other insulating materials included mica and glass. The endurance curves for all materials investigated leveled off only with the disappearance of corona. When corona is prevented, e.g., by excluding gases from the test region, the endurance curve is essentially flat in less than one hour. A theory to explain this behavior is proposed.

N8. A Zirconium Concentrated-Arc Infrared Source for Infrared Spectroscopy. M. B. HALL AND R. G. NESTER, *E. I. du Pont de Nemours & Company.*—Zirconium oxide concentrated-arc lamps have been enclosed in argon-filled, water-cooled jackets provided with rocksalt or thallium bromide-iodide windows. The arcs, so altered, have operated troublefree for thousands of hours as highly satisfactory infrared spot sources, particularly useful in infrared microspectroscopy. Since the sources are isolated in cool jackets, they can be placed near to mirrors, etc., when desired, for example, to provide magnified images of the same intrinsic brilliance. Examples are given illustrating applications in the infrared microspectroscopy of polymers.

SATURDAY MORNING AT 10:00

Chemistry 100

(JOHN BARDEEN presiding)

Invited Papers of the DSSP: Low Temperature Phenomena

O1. Supercurrents and Mean Free Paths. A. B. PIPPARD, *Cambridge University.* (40 min.)
O2. Experiments on Supraconducting Spheres. W. V. HOUSTON, *Rice Institute.* (30 min.)
O3. New Supraconducting Compounds. B. T. MATTHIAS, *Bell Telephone Laboratories.* (20 min.)
O4. Meissner Effect in Alloys. J. W. STOUT, *University of Chicago.* (30 min.)

Business Meeting of the Division of Solid-State Physics

SATURDAY MORNING AT 10:30

Physics 110

(M. L. POOL presiding)

Nuclear and Molecular Physics

P1. Positron Activity Arising from the Proton Bombardment of Mg^{25}.* LEONARD N. RUSSELL, WARREN E. TAYLOR, AND JOHN N. COOPER, *The Ohio State University.*—Thin targets of electromagnetically separated[1] Mg^{25} were deposited on a 0.0005-in. tantalum foil by vacuum evaporation. They were bombarded with protons from an electrostatic generator

for 45 seconds. The beam was then cut off and the positron activity measured over a period of 25 seconds, which corresponds to four half-lives of Al^{26} formed by proton capture in Mg^{25}. The yield of positrons per proton over the range 300 to 1050 kev indicates well-resolved maxima at 386, 489, 508, 560, 586, 650, 680, 722, 777, 812, 880, 924, 980, and 1043 kev. The 489, 560–586, and 812 resonances can be correlated with the early work of Curran and Strothers,[2] who used relatively thick targets. The values 386, 489, and 508 agree well with the later work of Tangen.[3] The other levels have not been previously reported.

* Assisted by a contract between the AEC and The Ohio State University Research Foundation.
[1] Supplied by the Carbide and Carbon Chemical Division, Oak Ridge National Laboratory.
[2] Curran and Strothers, Proc. Roy. Soc. (London) **A172**, 72 (1939).
[3] R. Tangen, Kgl. Norske. Videnskab. Selskabs. Skrifter No. 1 (1946).

P2. Technetium 98 and 100. R. A. House, R. L. Colligan, D. N. Kundu, and M. L. Pool, *The Ohio State University.*—Bombardments of all the enriched isotopes of molybdenum were made with 6.3 and 7.4-Mev protons. An activity of 42 ± 2 minutes produced from Mo^{97} and more strongly from Mo^{98} is assigned to Tc^{98}. The decay characteristics are 2.1 ± 0.1-Mev positrons by aluminum absorption, K-capture, β^+/K-cap.$\sim$1, two gamma-rays of energies 0.86 and 0.2 Mev by lead absorption and conversion electrons from the latter gamma-ray. The reported 2.8-day β^- activity is not confirmed to be Tc^{98} and is suspected to be chemical contamination of Mo^{99} which is produced with a very large yield from $Mo^{98}+d$ and $Ru+n$. A 17.5 ± 1-second activity was produced from Mo^{100} as also the known 14-minute Tc^{101} with a yield ratio$\sim$1. The former half-life characterized by negatrons of 2.4 ± 0.3 Mev and some gamma-rays is presumably assignable to Tc^{100}. Very short bombardments of Mo^{100} on internal probe targets failed to confirm the 1.3-minute Tc^{100}, whereas similar targets exposed to an external beam in the atmosphere showed an activity$\sim$1.3 minutes apparently caused by $N+p$ activities.

P3. Radiations of Niobium 96. D. R. Jones,* S. C. Fultz,† and M. L. Pool, *The Ohio State University.*—Nb^{96} was obtained by bombarding enriched $Zr^{96}O_2$ with protons. The beta-spectrum, internal conversion peaks, and photoelectron peaks were examined in a 180° spectrometer. The beta-spectrum was found to be complex, having two components, 0.686 ($\pm$0.005) Mev (92 percent) and 0.37 Mev (8 percent). Gamma-rays found by examining peaks from a uranium radiator have energies of 0.455, 0.545, 0.745, 0.9, and 1.045 Mev. Gamma-rays identified by internal conversion peaks are 0.745, 1.045, and 1.1 Mev. Coincidence measurements have been made on a scintillation spectrometer. A tentative decay scheme has been drawn up.

* Major, USAF.
† Fellow, National Cancer Institute.

P4. An Empirical Mass Surface. Alex E. S. Green, *The University of Cincinnati.*—Atomic masses for $A>10$, may be computed quite accurately by the use of the simple equation

$$M-A=\Delta_m(A)+\delta H(A)+\theta^2 J(A)$$
$$=100(\mathbf{A}-1)^3-62+\delta/\mathbf{A}^{\frac{1}{2}}+\theta^2/4\mathbf{A}\ (\text{in } mmu),$$

where $\mathbf{A}=A/100$, $\delta=+1, 0, -1$ according to nuclear type, $\theta=N-Z-D_m$ and $D_m=40\mathbf{A}^2/\mathbf{A}+2$. This empirical surface, which is an outgrowth and improvement of a nuclear energy surface previously used,[1] is useful for predicting unknown nuclear masses and Q values, for charting the irregularities of experimental masses in connection with studies of shell structure, for evaluating the accuracy of various semiempirical mass equations, and for simplifying computations based upon various semiempirical mass equations.

[1] A. Green, Phys. Rev. **83**, 1248 (1951).

P5. The Experimental Mass Surface. R. B. Minogue, R. Oppenheim and A. E. S. Green.—We develop a set of parameters to characterize the deviations of experimental masses from our empirical masses. The experimental mass data is then used to evaluate some of these parameters. The pairing functions $H(A)=36/A^{\frac{1}{2}}$ and $H(A)=10/A^{\frac{1}{2}}$ (in *mmu*) are examined and compared in the light of the experimental evidence. The experimental-empirical neutron binding energy residuals and the experimental-empirical proton binding energy residuals are examined, and an effort is made to interpret these residuals in terms of nuclear shell structure.

P6. The Mass Surface and Radioactivity. J. S. Nader, N. J. Marucci and A. E. S. Green, *The University of Cincinnati.*—Beta-decay energies may be used to evaluate some of the parameters which characterize the deviations of the experimental mass surface and the empirical mass surface. We first develop the formulas needed for such calculations. The results of an analysis of the experimental data are then given. The mass surface may be used to predict radioactive decay sequences involving alpha- and beta-particle emission. We compare various predicted chains with actual chains. The significance of the discrepancies is discussed.

P7. Semiempirical Mass Surfaces. N. Engler and A. E. S. Green, *The University of Cincinnati.*—The functions which characterize the differences between the semiempirical mass surface and our empirical mass surface are developed. These functions have been computed for seven different sets of constants which have appeared in the literature. These functions are then compared with the functions which characterize the differences between the experimental mass surface and the empirical mass surface. In this way we subject the semiempirical mass surfaces to microscopic examinations. We also present in graphical form the correction factors needed for the rapid computation of semiempirical mass values and Q values.

P8. Nuclear Quadrupole Interactions in the Microwave Spectrum of Hydrogen Azide.* John D. Rogers and Dudley Williams, *The Ohio State University.*—The rotational transition $J=0$ to $J=1$ in N_3H has been re-examined with a view to obtaining further information concerning the effects of nuclear quadrupole interactions. Although the problem of quadrupole effects in a molecule containing three nuclei with equal quadrupole moments has not yet been solved, it is found that in the case of N_3H all major features of the $J=0$ to $J=1$ transition can be explained in terms of the effects produced by a single N^{14} nucleus. The nucleus involved is presumably that of the end nitrogen atom and the interaction term $eQq=-4.67\pm0.04$ mc/sec as compared with -4.7 mc/sec in HCN and -4.67 mc/sec in CH_3CN. On the basis of a single quadrupole interaction, the ratio of frequency separations of the hyperfine structure components should be 1.50, whereas the observed value is 1.52 ± 0.04. If the present analysis is valid, the frequency of the unperturbed transition leads to a value $B+C=23{,}815.56\pm0.05$ mc/sec, which is in fair agreement with the value of Amble and Dailey, who obtained the value 23,815.7 mc/sec from the center of the incompletely resolved pattern but differs from our earlier value based on measurements of the Stark pattern.

* Supported in part by a contract between the Geophysical Division of the Air Force Cambridge Research Center and The Ohio State University Research Foundation.

P9. Absorption Bands of Atmospheric Carbon Monoxide.* J. H. Shaw and J. N. Howard, *The Ohio State University.*—Several investigators[1] have identified strong lines in the 4.7μ region of the solar spectrum with the fundamental band of atmospheric CO. For such an intensity of the fundamental band, laboratory measurements show appreciable absorption

in the overtone band.[2] However, lines of this expected intensity in the overtone region are not present in spectra taken at Lake Angelus, Michigan or Mt. Wilson.[3] Preliminary solar observations taken at Columbus, Ohio, in the overtone region also fail to show lines of the expected intensity. These results may be indicative of an anomalous intensity distribution between the fundamental and overtone bands under the conditions prevailing in the earth's atmosphere. Solar and laboratory data will be presented and discussed.

* Supported in part by a contract between the Geophysics Research Division of the Air Force Cambridge Research Center and The Ohio State University Research Foundation.
[1] M. V. Migeotte, Phys. Rev. **76**, 1108 (1949); M. V. Migeotte and L. Neven, Physica **16**, 123 (1950); Shaw, Chapman, Howard, and Oxholm, Astrophys. J. **113**, 268 (1951).
[2] S. S. Penner and D. Weber, J. Chem. Phys. **19**, 807 (1951).
[3] Mohler, Pierce, McMath, and Goldberg, *Photometric Atlas of the Near Infrared Solar Spectrum* (University of Michigan Press, Ann Arbor, 1951).

P10. Theory of the Ozone Molecule.* B. T. DARLING AND J. A. WEISS, *The Ohio State University.*—In the theory of the ozone molecule the three isomeric forms may be treated by the use of an angular coordinate x such that $x \rightarrow x + 2\pi/3$ corresponds to cyclic permutation of the nuclei. The potential energy must be an even function of x and have the period $2\pi/3$ similarly to the case of methyl alcohol. Here however, this potential leads to only a twofold degeneracy of the vibrational levels, descrived by periodic and "anti-periodic" wave functions; the former is associated with the even-K, the latter with the odd-K, where K is the component of angular momentum perpendicular to the plane of the nuclei. There are no interaction terms in the Hamiltonian connecting these two classes of states. If the equilibrium configuration is isosceles, the barrier against inversions is too high to produce observable splitting of the levels. We are analyzing the 1040 cm^{-1} band of the solar ozone spectrum, as observed by Howard and Shaw,[1] in the assumption of isosceles form such as that proposed by Hughes.[2] We are also investigating the possibility of a nearly-isosceles form (threefold double minimum) which may account for the presence of lines that would otherwise not appear in the spectrum.

* Supported in part by a contract between the Geophysical Division of the Air Force Research Center and The Ohio State University Research Foundation.
[1] J. N. Howard and J. H. Shaw, private communication.
[2] Richard H. Hughes, Am. Phys. Soc. Bulletin, Vol. 26 No. 6 (1951), abstract G 12.

SATURDAY MORNING AT 9:30

Physics 100

(R. SMOLUCHOWSKI presiding)

Metals

Q1. The Elastic Constants of a Cu-Si Alloy.* CHARLES S. SMITH AND J. W. BURNS, *Case Institute of Technology.*—The elastic constants of a Cu−4 atom percent Si single crystal have been determined by the pulsed ultrasonic method. The crystal† was in the form of a cylinder with end faces normal to [110]. Measurement of the two transverse wave velocities in this direction yields directly the two fundamental shear constants $C = c_{44}$ and $C' = (c_{11} - c_{12})/2$, and these when combined with the measured longitudinal velocity yield the compressibility K. The constants C and C' are significantly lower than those for pure Cu.[1] The differences ΔC and $\Delta C'$ have been considered, starting from Fuchs' theoretical calculation of the elastic constants of copper. Simple assumptions about the composition dependence of the important contributions to the elastic constants lead to reasonable conclusions. Similar considerations applied to the only previously measured face centered copper base alloy, Cu−28 percent Zn are consistent.

* Work supported by ONR.
† Furnished and prepared by B. L. Averbach, MIT.
[1] D. Lazarus, Phys. Rev. **76**, 545–553 (1949).

Q2. A Study of the Hafnium-Hydrogen System. S. S. SIDHU AND JOSEPH C. MCGUIRE, *Argonne National Laboratory.*—A series of hafnium samples containing 2 to 66 atomic percent hydrogen was prepared and studied by the x-ray diffraction and the microscopic methods. The limit of solubility of hydrogen in hafnium, the number of stable hydrides formed, and their x-ray diffraction data and densities were determined. The lattice parameters and the number of molecules per unit cell of each hydride were calculated, and tentative crystal structures are proposed. The limits of compositions within which each phase exists are given.

Q3. Atomic Arrangements in Gold-Nickel Solid Solutions.* P. A. FLINN AND B. L. AVERBACH, *M.I.T.*—Absolute measurements of the diffuse x-ray scattering from polycrystalline single phase gold-nickel alloys have been made using a Geiger counter spectrometer. The observed intensity distribution, anomalous in terms of simple short range order theory, has been satisfactorily interpreted as a combination of short range order and a "size effect." A modification of the usual Fourier transform procedure has been developed which permits separate evaluation of the short range order coefficients and of the size effect coefficients, which are a measure of the actual atomic sizes in the solid solution. Since the observed short range order is of the copper-gold type opposite to that predicted for this system by the quasi-chemical theory, this type of theory is inapplicable, and an interpretation of the thermodynamic properties of the system in terms of elastic energies appears necessary.

* Research sponsored by AEC.

Q4. Order Disorder Theory.* DWAIN BOWEN, *North American Aviation, Inc.*—An equilibrium theory of order disorder has been formulated that includes the effect of lattice oscillations on the ordering process. The order parameter is defined in terms of long range order. The usual assumption of linearity of ordering energy on order parameter has been abandoned in favor of an empirical determination from internal energy measurements. This new ordering energy is related to short range ordering forces. Detailed calculations on $AuCu_3$ indicate that the contributions to ordering from lattice oscillations arise from a change in Debye temperature with order of approximately five percent. This small change, however, contributes appreciably to the ordering, particularly in the region near zero order where the persistance of order above the critical temperature may be explained. A theory of the rate of ordering or disordering has been formulated that is consistent with the equilibrium theory discussed above. (The Bragg relaxation equation is not consistent with equilibrium requirements for disordering.) The anomalies of order-

ing rates in $AuCu_3$ find at least qualitative explanation in this formulation. The absence of order in Au_3Cu and the inability to quench in disorder in β-brass will be discussed.

* Work carried out under contract with the AEC.

Q5. Short Range Order Diffuse Scattering in Al-Zn.* PETER S. RUDMAN, PAUL A. FLINN, AND B. L. AVERBACH, *M.I.T.*—Measurements have been made of the x-ray diffuse scattering from polycrystalline samples of Al-Zn alloys at temperatures above the solubility gap in the alpha FCC region. The experimental technique combines data from a Geiger counter spectrometer with film data obtained from transmission samples. The diffuse scattering shows a large small angle component which can be interpreted in terms of clusters of like atoms within the solid solution. A Fourier transform method is used to evaluate the x-ray data, and the results indicate an excess over random of like nearest neighbors. This preference for like neighbors is believed to arise from clusters of like atoms in the solid solution. This tendency toward clustering is in agreement with predictions of the quasi-chemical theory. Similar effects have been observed in Al-Ag alloys.

* Research sponsored by AEC.

Q6. Neutron Diffraction Studies of Cold-Worked Brass. R. J. WEISS, *Watertown Arsenal*, J. R. CLARK, *U. S. Naval Postgraduate School*, J. HASTINGS AND L. CORLISS, *Brookhaven National Laboratory**.—Recent x-ray studies of cold-worked aluminum by Hall and Williamson and of cold-worked brass by Warren and Averbach are in disagreement as to the type of extinction causing variations in intensity of the low index peaks in annealed and cold-worked samples, the former postulating secondary extinction, the latter primary. Since thermal neutrons exhibit negligible extinction effects for powdered metals, powder patterns have been taken of the 111 and 200 peaks in cold-worked and annealed brass. The intensities of the peaks are found to agree to within 1 percent in support of Averbach and Warren. In addition, a new technique of examining the Bragg discontinuities which occur in neutron transmission studies at long wavelengths has substantiated the nature of the broadening to be mostly lattice distortion. A second point of disagreement, though, between the above authors is that Averbach and Warren have found no change in the diffuse background whereas Hall and Williamson find an increase in the cold-worked samples. To resolve this difference, transmission studies are being made with very long wavelength neutrons beyond the Bragg region. Any difference in transmission between cold-worked and annealed specimens is then directly attributable to diffuse scattering.

* Research carried out under contract with AEC.

Q7. Effect of a Low Absorption Coefficient on X-Ray Spectrometer Measurements.* D. T. KEATING AND B. E. WARREN, *M.I.T.*—In x-ray spectrometer measurements with a flat sample, if the absorption coefficient is low, diffraction takes place in the interior of the sample as well as in the surface layer, resulting in an asymmetric broadening and displacement of the measured peak. The effect can be corrected by a simple expression involving only the measured peak shape and its derivative. The effect can also be corrected by the Stokes method of Fourier analysis, and values of the Fourier coefficients for the low absorption effect are presented by plots covering a suitable range of experimental conditions.

* Sponsored by AEC under Contract.

Q8. Effect of Cold Work on X-Ray Patterns of Aluminum.* M. MCKEEHAM, B. L. AVERBACH, AND B. E. WARREN, *M.I.T.*—X-ray studies of cold-worked and annealed filings of aluminum have been reported[1] which indicate a background level for the cold-worked sample about 15 percent higher than that for the annealed material. Measurements have been made with crystal monochromated $CuK\alpha$ on annealed and non-annealed flat pressed compacts of aluminum filings without binder. There is a small broadening of the peaks from the non-annealed sample, but except in the immediate vicinity of the peaks there is no measurable difference in background level for the annealed and nonannealed samples. The same absence of any difference in background has been found with single crystals of aluminum in the initial state and after cold work.

* Sponsored by AEC under Contracts.

[1] W. H. Hall and G. K. Williamson, Proc. Phys. Soc. (London) **64B**, 946 (1951).

Q9. The Separation of Cold Work Distortion and Particle Size Broadening in X-Ray Patterns.* B. E. WARREN AND B. L. AVERBACH, *M.I.T.*—For an x-ray reflection in which there is both particle size and distortion broadening, the shape can be represented by a Fourier series whose coefficients are the product of two coefficients, one relating to particle size only and the other to distortion. The distortion coefficient depends upon the order of the reflection, while the particle size coefficient is independent of order. The two effects can be separated by measuring at least two orders of a reflection, and plotting $\ln A_n(l)$ *vs* l^2 where l is the order of the reflection. The intercept at $l^2=0$ gives the coefficient for particle size only. This method of separation is completely general in that it does not involve any assumption about the peak shape. A single crystal of Cu−2 percent Si rolled to 50 percent reduction gives intercepts corresponding to an average particle dimension $\bar{L}=1000$A. The major part of the broadening is due to distortion, the particle size broadening is small but not small enough to neglect.

* Sponsored by AEC under Contracts.

Q10. Elastic and Plastic Properties of Very Small Metal Specimens. J. K. GALT AND CONYERS HERRING, *Bell Telephone Laboratories*.—Very thin whiskers of tin ($r=0.9\times10^{-4}$ cm) often grow from tin platings.[1] We have examined the elastic and plastic properties of these whiskers and find them to show properties very near those to be expected from theoretically perfect crystals. Strain of 1 percent has been produced in these whiskers without plastic deformation. A strain of 1/2 percent was held in one whisker for a week and, it also recovered elastically. At strains of 2 or 3 percent deformation occurs. This plastic deformation consists of a bend which is quite sharp. Slides will be shown.

[1] Compton, Mendizza, and Arnold, Corrosion **7**, 327 (1951).

Q11. Kinetics of Grain Boundary Diffusion. R. SMOLUCHOWSKI, *Carnegie Institute of Technology*.—According to the proposed model of a grain boundary the more or less regular array of dislocations applicable at small angles of disorientation changes with increasing angle into rod-like bunches of dislocations which eventually transform into islands of fit and misfit. An approximate solution of the diffusion equation is obtained for the various ranges of the disorientation angle, and it is shown that the apparent activation energy for grain boundary diffusion can be expressed in terms of E_B and E_V which are respectively activation energies for diffusion in the grain boundary material itself and in the grains. For the rod-like bunches one obtains very low, or even negative, apparent activation energies which increase with increasing angle. These results are in good agreement with data obtained on grain boundary diffusion of zink in copper.

Q12. Diffusion of Silver and Antimony in Silver.* L. SLIFKIN, D. LAZARUS, AND T. TOMIZUKA, *University of Illinois*.—Measurements of self-diffusion of silver 110 in pure polycrystalline silver are described. The results are compared with those of Hoffman and Turnbull.[1] The activation energy

for grain boundary diffusion obtained by these investigators is very close to reported activation energies for the diffusion of many metals into polycrystalline silver. It is therefore of value to study the diffusion of these metals into single crystals of silver. Some preliminary results of the diffusion of antimony 124, at extremely low concentrations, into single crystal silver are presented.

* Supported in part by the AEC.
[1] R. E. Hoffman and D. Turnbull, J. Appl. Phys. **22**, 634 (1951).

Q13. The Optical Properties of Evaporated Antimony Films. CALVIN TILLER AND HENRY LEVINSTEIN, *Syracuse University.*—The optical properties of evaporated antimony films at various wavelengths have been studied as a function of rate of evaporation and film thickness. The dependance of the structure of antimony films on the rate of evaporation has been studied by Levinstein.[1] Reflectivity and transmissivity for the various types of films have now been measured. Antimony is evaporated in a high vacuum onto a quartz substrate. All optical measurements are made first in the vacuum system immediately after evaporation and are repeated later in air. Film thickness is measured by multiple beam interferometry. Below 100A films are always amorphous, between 100 and 400A films are crystalline for rapid evaporation rates and amorphous for slow evaporation. Above 400A films are always crystalline. Amorphous films are brown while crystalline films have a grey, metallic luster. Amorphous films show greater transmissivity but smaller reflectivity than crystalline films. Very slowly evaporated amorphous films have a greater transmissivity and smaller reflectivity than amorphous films evaporated more rapidly. The optical properties of crystalline films are not influenced by their rate of formation. Both reflectivity and transmissivity vary more rapidly with wavelength for amorphous than for crystalline films.

[1] H. Levinstein, J. Appl. Phys. **20**, 306 (1949).

Q14. Effect of Thickness of Thin Metal Films on the Mean Free Path of Conduction Electrons.* E. C. CRITTENDEN, JR., E. H. LAYER, AND R. W. HOFFMAN, *Case Institute of Technology.*—Measurements of the temperature coefficient of resistance of evaporated films of nickel and copper indicate that the mean free path l of the conduction electrons is a function of thickness t. A simple theoretical model predicts $l=\gamma l_\infty^2/t$, where l_∞ is the mean free path for a thick slab, and γ is an adjustable parameter. Theoretical values of the temperature coefficient of resistance predicted on this basis fit the experimental data well. The usual assumption of constant mean free path[1,2] gives serious disagreement. In contrast, values of the resistivity, ρ, predicted on the basis of constant mean free path, agree approximately with experimental values, as others have also reported.[1,3] The introduction of variable mean free path alters the theoretical curves for ρ very little and accounts for the previous apparent agreement.

* Supported by the ONR.
[1] Klaus Fuchs, Proc. Cambridge Phil. Soc. **34**, 100 (1938).
[2] E. H. Sondheimer, Phys. Rev. **80**, 401 (1950).
[3] P. G. Wilkinson, Jour. Appl. Phys. **22**, 419, (1951).

SATURDAY AFTERNOON AT 2:00

Physics 110

(R. BUCHDAHL presiding)

Contributed Papers of the DHPP

R1. Structure and Properties of Polyamides. R. BRILL, *Polytechnic Institute of Brooklyn.*—The structure of polyamides will be discussed as a result of new x-ray investigations. The importance of the hydrogen bond will be illustrated by means of the thermal behavior, the tensile strength, and the interaction of water with polyamides.

R2. The Specific Heat and Degree of Crystallinity of Polychlorotrifluoroethylene. JOHN D. HOFFMAN, *General Electric.*—The specific heats of slow-cooled and air-quenched samples of polychlorotrifluoroethylene (mp~210–212°C) have been measured between 0°C and 250°C in a differential calorimeter. The calorimeter is described. By comparison of the experimental heat of fusion with the heat of fusion of the pure crystalline polymer obtained from Flory's theory by Bueche, the degree of crystallinity at 0°C was found to be 0.82 ± 0.07 for the slow-cooled sample, and 0.35 ± 0.03 for the air-quenched sample. The enthalpies of the pure crystals and supercooled liquid polymer were obtained as functions of temperature by a simple interpolation procedure. Comparison of these enthalpies with the observed enthalpies permitted the degree of crystallinity of both the air-quenched and slow-cooled polymer to be calculated as a function of temperature. The results for the slow-cooled sample were in good agreement with those obtained by Price by a volume method. The quenched sample showed a distinct tendency to crystallize on warming. Reasons were advanced for believing that the glass transformation temperature for this polymer is below −80°C.

R3. Sedimentation and Diffusion of Polyelectrolytes. B. ROSEN AND F. R. EIRICH, *Polytechnic Institute of Brooklyn.*—The interpretation of the sedimentation and diffusion rates of flexible particles is complicated by the simultaneous influences of charge and shape. Although there are theories of these two effects separately, there is no instance where work of the combined effect is reported. Experimentally, there is the difficulty that charge and shape cannot be varied independently. Measurements were carried out on a fraction of polyvinyl *N-n* butyl pyridinium bromide as a function of *p*H and ion concentration. The combination of sedimentation and diffusion data with values obtained from electrophoretic measurements, together with a knowledge of the molecular weight, permit the calculation of the effective charge as well as of the frictional constant. The axis ratios obtained from the latter by means of a modified equation is in agreement with the axial ratio obtained from viscosity measurements.

R4. Relations Between Viscosity and Flow Birefringence of Polyelectrolytes. P. M. KAMATH, B. ROSEN, AND F. R. EIRICH, *Polytechnic Institute of Brooklyn.*—The intrinsic viscosities, dilution curves, the extinction angles, and the flow birefringence were measured as a function of concentration on a high molecular weight fraction of poly-4-vinyl *N-n* butyl pyridinium bromide. The observed concentration dependence is so strong as to render the calculation of a rotary diffusion constant impossible. The form of the viscosity concentration curves indicates that in dilution experiments one might never reach the concentration range for independent

particles, within the experimental accuracy attainable. The inference from this data is that present views on the behavior of polyelectrolytes may as yet not distinguish clearly between concentration effects and the behavior of individual particles.

R5. Polystyrene Molecular Weight Distribution by Turbidity Titration and the Effect on This Distribution of Variations in the Preparation of the Polymers. ARTHUR F. ROCHE, JR., *Dow Chemical Co.*—A turbidimetric method for determining the molecular weight distribution of polystyrene is described. The solvent is ethyl benzene; the precipitant is amyl alcohol. The calibration of the equipment and a discussion of some of the possible errors are considered. Calculation of the results is explained, including the use of IBM machines. A useful method for graphing distribution curves to show relative sharpness is a feature of the method. The effects of temperature of polymerization and percent conversion on the molecular weights are shown, as well as correlations of calculated number and weight average molecular weights, with osmotic and light scattering molecular weights, respectively. The curves are compared with those obtained with other solvents as well as with those obtained by standard fractionation procedures.

R6. A New Molecular Weight Distribution Technique for Polystyrene. Part II. Experimental Results. R. F. BOYER, *Dow Chemical Company.*—The molecular weight distribution curve of a polymer-homologous soluble polystyrene can be obtained by observing the cumulative volume of precipitate, which corresponds to increasing additions of nonsolvent to a dilute solution of polymer.[1] Two general experimental techniques will be described. In one case, daily increments of nonsolvent are added to a single contaiher of the polymer solution; in the second method, varying amounts of nonsolvent are added simultaneously to 12 containers of polymer solution. The latter method is much more rapid, but also less likely to represent equilibrium data. The two methods are in substantial agreement if the initial concentration of polystyrene is around 0.1 percent. Most of the polystyrene samples examined thus far are showing multiple peaks in their molecular weight distribution curves, essentially confirming the earlier results of Gralén and Lagermalm.[2]

[1] R. F. Boyer, J. Polymer Sci. **8** (January, 1952).
[2] N. Gralén and G. Lagermalm, Chem. Abstracts **42**, 5257 (1948).

R7. Configuration Distribution of a Chain Molecule with Correlations. C. M. TCHEN, *National Bureau of Standards.*—We consider first, a correlation covering the whole chain of the type c^{j-i} between the ith and jth links, where c is a partial correlation between the neighbor links. Thus, the configurations of the chain are controlled by Markoff processes. If r is the end-to-end distance of the chain, the high order moments of r can be studied by the theory of combinations. The monents show that the distribution is Gaussian for an infinite number of links and not extremely large values of r. From this result, we can show also the validity of the central limit theorem in its extension to Markoff processes. Next we take the random walk as a model of the chain configurations, and extend the concept of correlation to long range effects and non-Markoff processes. For this purpose, we consider a random walk with restricted occupancy: a directional preference occurs in regions of excessive accumulation of density. If, in the one dimensional problem of random walk, we allow a limit of accumulation of density at any spot, a large number of "pockets" will be isolated between hindrances, inaccessible to the development of the random walk. The expansion of the configurations is studied by the correlation which exists between the paths at the hindrance points.

SATURDAY AFTERNOON AT 2:00

Physics 100

(P. W. ANDERSON presiding)

Invited Papers of the DSSP: Second-Order Phase Changes

S1. Progress in Computing the Statistics of Cooperative Assemblies. G. H. WANNIER, *Bell Telephone Laboratories.* (40 min.)

S2. The Thermodynamics of Phase Transitions. L. TISZA, *M.I.T.* (30 min.)

S3. Phase Transitions in the Ammonium Halides. H. A. LEVY, *Oak Ridge National Laboratory.* (30 min.)

S4. Influence of Pressure on Some Electron Phenomena in Solids. A. MICHELS, *University of Amsterdam.* (30 min.)

S5. Cooperative Effects in Paramagnetic Crystals Having Low Critical Temperatures. C. G. B. GARRETT, *Harvard University.* (30 min.)

SATURDAY AFTERNOON AT 2:00

Chemistry 100

(A. LANDE presiding)

Invited Papers in Molecular Spectroscopy

T1. Survey of the Spectrum of Water-Vapor. D. M. DENNISON, *University of Michigan.* (45 min.)

T2. The Infrared Spectra and the Molecular Structure of Pyramidal Molecules. H. H. NIELSEN *The Ohio State University.* (45 min.)

Post-Deadline Papers, if Any

SATURDAY AFTERNOON AT 2:00

Chemistry 161

(R. S. SHANKLAND presiding)

Transactions of Crystals and Light

U1. Optical and Electrical Properties of Edge Emission in Cadmium Sulfide. CLIFFORD C. KLICK, *Naval Research Laboratory.*—Measurements of optical transmission, photoconductive response, luminescent edge emission, and excitation spectrum for edge emission have been made on single crystal specimens of CdS at 77K° and 4K°. At the lowest temperature there is an energy gap between the absorption edge and the onset of emission of more than 0.1 electron volt. The excitation spectrum shows three peaks of which two also appear in the photoconductive measurements. The third excitation peak occurs at 0.1 electron volt to the low energy side of the main excitation and photoconductive peak. This may be compared with the rough theoretical prediction of an energy gap of 0.2 electron volt between the lowest exciton level and the bottom of the conduction band.

U2. An Interpretation of the Absence of *F'* Centers in KCl and KBr X-Rayed at 4°K. JORDAN J. MARKHAM, *Johns Hopkins University.**—Recent data by Dutton, Heller, and Maurer[1] indicated that *F'* centers in KCl do not form during x-radiation at liquid helium temperature. This is also true for KBr.[2] *F'* centers form at liquid nitrogen temperature during x-radiation in both crystals. These conclusions have have prompted a re-examination of Peck's[3] earlier data on the formation of *F'* centers in additively colored crystals. These data indicate that *F'* centers should form at liquid helium as well as at liquid nitrogen temperature. The absence of these centers at liquid helium temperature seems to indicate that negative ion vacancies are formed during the x-raying process. If this interpretation is correct, we may conclude that the x-rays produce negative ion vacancies as well as free electrons.

* This research was supported by the Bureau of Ordnance, U. S. Navy.
[1] Dutton, Heller, and Maurer, Phys. Rev. **84**, 363 (1951).
[2] W. Duerig and J. J. Markham, Conference on the Electrical and Optical Properties of Ionic Crystals, Urbana, Illinios (1951).
[3] H. Pick, Ann. Physik **37**, 421 (1940).

U3. An Experimental Search for Self-Trapped Electrons in the Alkali Halides.* WILLIAM H. DUERIG, *University of Maryland and Johns Hopkins University.*—Calculations for NaCl of self-trapped electrons, first proposed by Landau, indicate that to a first approximation, these electrons should be thermally stable at liquid helium temperatures. NaCl, KCl, and KBr were x-rayed at these temperatures and their optical absorption spectra examined from the *F* band in the visible to the infrared absorption limits of the crystals. The 1- to 3.5-micron region was measured on a rapid scanning spectrometer[1] to preclude the bleaching of any centers before the measurement was completed. The rest of the spectrum was obtained with conventional Beckman and Perkin-Elmer spectrophotometers. No optical absorption bands were found. Hence one can conclude that stable self-trapping centers do not exist in sufficient quantities at temperatures down to liquid helium to be detected by the sensitivity of our instruments. If these centers do exist, it may be only at lower temperatures, or they may rapidly diffuse through the crystal during x-raying until they form a more stable center, e.g., *F* center.

* This research was supported by the Bureau of Ordnance, U. S. Navy.
[1] B. W. Bullock and S. Silverman, J. Opt. Soc. Am. **40**, 608 (1950).

U4. Preparation and Properties of Indium Sulfide Phosphors.* D. C. REYNOLDS, C. S. PEET, AND A. E. MIDDLETON.—Indian sulfide phosphors have been prepared from In_2S_3, made by direct combination of indian and sulfur and also by wet chemical methods. The In_2S_3 powders have a deficit-type spinel structure. Extra x-ray diffraction lines were observed; these have been attributed to free sulfur in the samples. A single crystal of In_2S_3 was grown; this sample also gave a deficit-type spinel structure. However, in this case, extra diffraction lines were not observed. The unit cell size a_0 for the single crystal was 10.790 ± 0.002A; for the powdered samples, a_0 was 10.75A. Phosphors were prepared from the In_2S_3 samples by firing with NaCl+MgF flux materials and an activator. The firing was done in a vacuum at approximately 900°C. The powdered material sublimed at this temperature and the luminescent material condensed in a region at approximately 550°C. Material condensing in regions at different temperatures was not luminescent. The luminescent material is excitable by both ultraviolet radiation and particle bombardment. The copper-activated material has an emission peak at 5850A. This phosphor contains two phases, one being the β-phase described above, the other a nonisotropic phase that has not been identified.

* This work was supported by Consolidated Mining and Smelting Company of Trail, British Columbia.

U5. Electrical and Optical Properties of Single Crystals of Zinc Sulfide. WM. W. PIPER AND FERD E. WILLIAMS, *General Electric Research Laboratory.*—Single crystals of zink sulfide have been grown by a modification of the technique described by Reynolds and Czyzak.[1] Zink sulfide powder is sublimed at 1185°C, and single crystals $1\times1\times3$ mm have been grown from the vapor phase on a quartz wall at 1080°C. The crystals are essentially the Wurtzite-structure with some stacking disorders. The room temperature dark conductivity of a typical crystal previously exposed to room light is 10^{-11} mho/cm. After heating such a crystal to 300°C in the dark to empty traps, measurements of conductivity from 200 to 500°C indicate intrinsic semiconductor characteristics with a thermal band gap of (3.75 ± 0.1) ev. The optical absorption edge of these crystals is at (3.67 ± 0.03) ev. The photoconductivity spectrum has been measured and a peak is observed at 3.68 ev with a 0.069 ev half-width. Single crystals of copper-activated zink sulfide prepared by this technique luminesce upon application of ac or dc fields. Brightnesses up to 50 millilamberts have been measured at 60 cps and 10^5 v/cm. Variation of the light output as a function of voltage, current, and frequency will be discussed. A mechanism for electroluminescence will be proposed.

[1] D. C. Reynolds and S. J. Czyzak, Phys. Rev. **79**, 543L (1950).

U6. Multiple Time Constants in Photoconductivity. W. W. SCANLON, R. L. PETRITZ, AND F. L. LUMMIS, *U. S. Naval Ordnance Laboratory.*—The response time characteristics for photoconductivity in semiconductors of the PbS and PbTe type have been studied using both frequency and transient methods. The results, interpreted in terms of a numbers theory indicate that the response time in PbS may be characterized by a single time constant obeying a monomolecular law (exponential decay). In PbTe the response is best described by two time constants, one obeying a monomolecular law and the other obeying a bimolecular law (hyperbolic decay). A simple model leading to two time constants of the above type

consists of a conduction band and two lower energy states, one of which may be the normally filled band. The bimolecular law results from transitions between the normally filled band and the conduction band. The monomolecular law results from transitions between the conduction band and localized impurity states, a large number of which are unoccupied. While the experiments described here can be adequately interpreted in terms of a numbers theory, further experiments are required in order to reach conclusions regarding the relative merits of the barrier theory and the numbers theory of photoconductivity.

U7. The Relation between Noise and Response Time in Photoconductors: I. Theory. R. L. PETRITZ,* *U. S. Naval Ordnance Laboratory.*—Changes in the average intensity of illumination falling on a photoconductive cell produce corresponding changes in the equilibrium member of conduction electrons. The rate of approach to the new equilibrium state depends upon the cross section for photon absorption and the cross sections for electron recombinations. Fluctuations in the number of conduction electrons occur in a photoconductor in equilibrium with the radiation field. The rate at which these fluctuations occur depends on the same cross sections mentioned above. These considerations from the basis of our claim that the power spectrum of the current noise associated with fluctuations in the number of conduction electrons should be of the same form as the frequency response of a photoconductor to a light signal. This correspondence is proved for the general case where the radiation field interacts with a heat bath and with the photoconductor by use of the recombination equations of the theory of photoconductivity and the equations of the theory of current noise. The equation of the current noise power spectrum contains explictly the mobility and time constants; therefore from noise measurements it should be possible to obtain numerical values for these quantities.

* Also Catholic University, Washington, D. C.

U8. The Relation Between Noise and Response Time in Photoconductors: II. Experiment. F. L. LUMMIS AND R. L. PETRITZ,* *U. S. Naval Ordnance Laboratory.*—Response time and noise characteristics have been measured at temperatures from liquid air to room temperature on PbS cells. Response time studies show an increase of time constant, τ_R, with decreasing temperature. The noise measurements were made with two systems: a visual short-time average of a fluctuating meter deflection and a recorded long-time average involving a thermocouple as the noise power sensitive device. The noise spectrum has been found to be similar in form to the frequency response curve for photoconductivity. At the low frequency end, there is a slope much less than indicated by a $1/f$ law. This is followed at higher frequencies by a horizontal region which then goes smoothly through a 3 db per octave slope to a slope which is greater than a $1/f$ law. This limiting slope has not been accurately determined. A time constant, $\tau_N = 1/2\pi fo$, has been calculated directly from the noise curve where fo is the frequency at which the slope is 3 db/octave. τ_N was found to increase with decreasing temperature and agrees in magnitude with τ_R. The mobility has been calculated using the theoretical expression for the noise and is in the range of 2–3 cm²/volt-sec.

* Also Catholic University

U9. The Impedance of Semiconducting Films. J. N. HUMPHREY, F. L. LUMMIS AND W. W. SCANLON, *U. S. Naval Ordnance Laboratory.*—The determination of activation energy values of semiconductors by the method of dc resistance measurements on thin films is discussed. Evaporated films 10^{-3} to 10^{-4} mm thick are known to consist of microcrystallites in partial disorder. This structure produces relatively high contact resistance between crystallites, together with an intercrystalline capacitance. An equivalent electrical circuit based on the above structure was used to calculate the resistance as a function of frequency. Impedance measurements from dc to 200 mc are presented for films of tellurium, lead telluride, and lead sulfide. The intercrystalline capacitance was found to be of the order of 0.5 mmfd per square. Resistance-temperature data obtained from both dc and ac measurements will be presented for Te. Dc resistance measurements, which gave a $\log R$ *vs* $1/T$ curve linear over three decades of resistance indicated an intrinsic activation energy of 0.43 ev. Over this same temperature range, however, measurements of resistance at 10 mc show that the film was not in the intrinsic region. It is concluded that the usual dc resistance measurement is a questionable method for determining activation energy in thin films of semiconductors.

SUPPLEMENTARY PROGRAMME

SP1. Application of the Quantum-Mechanical Franck-Condon Principle to Complex Systems. MELVIN LAX, *Syracuse University and the Naval Research Laboratory.**—Many vibrational systems—crystals, molecules—are adequately described by normal modes and a quadratic Hamiltonian. If, in addition, the energy difference between two electronic states is a linear function of the vibrational coordinates, then the calculation of the absorption or emission spectrum can be calculated in an all quantum-mechanical fashion. The summation over all possible final states (involving emission or absorption of large numbers of phonons) *consistent* with conservation of energy is performed *exactly* with the help of an integral representation for the energy conservation delta-function. The quantum-mechanical absorptoin or emission spectrum is found to have the same peak (mean-value) and breadth (second moment) as the corresponding semiclassical spectrum discussed in an earlier abstract. However, the quantum-mechanical spectrum is not Gaussian but possesses odd moments of all orders and higher order even moments that do not quite agree with a Gaussian curve. The skewness (third moment) is positive for absorption and negative for emission (i.e., the high frequency tail is longer on absorption). And the kurtosis (fourth moment) is larger than that of the semiclassical Gaussian curve. Thus for the *same* rms width, the quantum-mechanical curve is flatter and longer tailed.

* To be given after Session C if the Chairman rules that time permits.

SP2. On Thermal Expansion of Water. GEORGE ANTONOFF.*—In thermal expansion of water, changes of curvature can be observed at intervals just as in other liquids.[1] They transpire in figures of all authors (on this subject a paper will soon appear exploring the whole field). Kretschmer disputes the kink at 50°C, which can be put into evidence by three or four independent methods and is supported by Magat in an indirect way, indicating an anomaly in this region. In every sense this case is analogous to that of benzene, and in standard conditions the kinks are reproducible. Kretschmer obviously worked in conditions which could give only indefinite results; but even he gives a curve with a noticeable disturbance at 50°C.

* To be given after Session C if the Chairman rules that time permits.
[1] Compt. rend, December 3, 1951.

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